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NOISE

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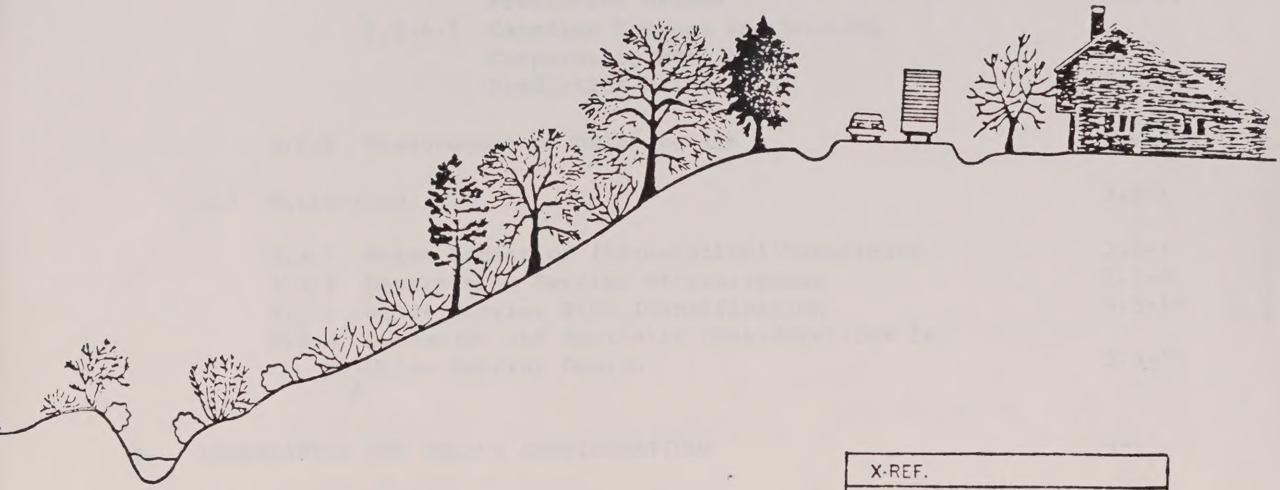

VOLUME 5B
NOISE

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Ministry of
Transportation &
Communications
Ontario

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Environmental
Office

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1. INTRODUCTION

This guideline has been developed primarily to meet the specific needs of Ministry of Transportation and Communications highway planners and designers. This does not necessarily preclude its adaptation by others outside the Ministry. It is not a formal directive with respect to methodology or noise standards.

The guideline first provides the user with a basic understanding of the more pertinent technical and non-technical aspects of highway noise in general. It then provides a systematic process through which the planner or designer can incorporate the identification and quantification of noise impacts (problems) and the evaluation of mitigation measures (solutions) into a specific project planning or design activity.

This document is a second revised edition of the Environmental Guidelines for Noise Considerations in Highway Planning and Design. In preparing this guideline, a significant amount of material has been drawn from the original report, reinforced by further research and policy completed since the first edition was issued.

Over the past several years much experience has been gained by transportation agencies in general, and this Ministry in particular, in the field of highway noise. Though the subject is advancing rapidly and present conclusions are subject to change, knowledge and techniques exist for defining or predicting noise problems and for evaluating noise attenuating measures from the viewpoint of cost and effectiveness. The measures for reducing highway noise problems are based on minimizing the number of people exposed to unacceptable noise levels through land use controls, through highway planning and design, through the construction of noise barriers, and through other noise attenuation methods. As public concern for noise and its control increases, it becomes even more important that planners and designers of transportation systems as well as those in land use planning, have an understanding of noise, its effects, and methods that can be used to reduce it.

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2. OBJECTIVES

The basic objective of these guidelines is to provide the Environmental, Planning and Design staff of MTC, and consultants with information which:

- assists in an understanding of the terminology used when dealing with problems of noise.
- outlines the factors which are pertinent to the determination of noise impacts.
- assists in the measurement and/or prediction of traffic noise levels.
- assists in the determination of measures which may be incorporated for the reduction (attenuation) of noise on a project specific basis.
- assists, through the use of a flowchart, in the assessment of highway noise problems, and the evaluation of methods used to prevent or reduce such problems.

3. BACKGROUND

3.1 Theory

3.1.1 General Information About Sound

Some of the basic definitions, physical and mathematical facts are summarized here to aid in a fuller understanding of noise problems.

Sound

- is a form of energy, and a measure of this energy is the sound pressure squared (p^2). The sound pressure at any instant is the pressure above or below ambient pressure.
- is transmitted from a source to a receiver by means of rapid air fluctuations.

Noise

- is undesirable or unwanted sound. Problems associated with noise are the annoyance it may cause; interference with conversation, leisure, or sleep; decreased work efficiency and proficiency in both physical and mental tasks; and potential or actual hearing loss.

Sound Measurement

Three basic characteristics of sound are normally utilized in its description.

1) the root mean square of the pressure fluctuations
2) the frequency of the fluctuations
3) the statistical distribution of the sound level

- in order to better understand the measurement of sound we can look at it in terms of the amount of energy involved. The intensity of sound at any point can be measured in terms of energy flow per unit area, e.g.: watts per square metre.
- sound intensities cover an enormous range.

It should be noted that any number can be expressed as ten to the power of something. This is termed as Exponent Representation. For example, 100 is 10 to the power of 2 (i.e. $100 = 10^2$). Another example is - 0.01 is 10 to the power of minus 2 (i.e. $0.01 = 10^{-2}$).

e.g.: - the quietest sound that most people can hear is 0.000000000001 watts/m^2 (10^{-12} watts/m^2)

- one of the loudest audible sounds is a jet aircraft at 50 metres which is 10 watts/m^2 (10^1 watts/m^2), a Saturn Rocket lift off at 100 metres is over 100,000,000 watts/m^2 (10^8 watts/m^2).

To deal with sound intensities over this type of range requires some mathematical adjustment. The form this adjustment takes can be followed through the following steps: -

1. Express sound intensities as a ratio using 'quietest sound' (10^{-12} watts/m^2) as a reference, and note the number of tenfold increases to which the reference intensity must be subjected for it to equal the intensity we are measuring.

   e.g.: the jet aircraft mentioned above is 10,000,000,000,000 (10^{13}) times as intense as the reference, or 13 times a tenfold increase.

   - we refer to a tenfold increase as a "bel" and this is the unit in which to express the ratio.

     e.g.: the intensity of the jet aircraft noise is 13 Bels.

   - The Bel is a rather large unit and so is divided into 10 sub-units called decibels.

     Thus the jet noise now is 130 decibels (written as 130 dB), or more accurately to avoid ambiguity with any other reference intensity:

     130 dB re 10^{-12} watts/m^2

2. Unfortunately this ratio is not always easy to calculate unless we use logarithms, which are worked out in terms of 'tenfold increases'.

How logarithms work: - By definition, if $a^b = c$, then the logarithm of c to the base a equals b. This is expressed in mathematical terms as:

$$\log_a c = b$$

for example: $\log_{10} 1000 = 3$.

Generally, for noise purposes, the number 10 is used as the base 'a'. Therefore, logarithms can be written as:

$$\log_{10} c = \log c$$

It is not necessary to continue to write 'to the base 10'. The most common base number is 10 and therefore is assumed unless otherwise mentioned.

The definition of Intensity Level in decibels can now be written as:

Intensity Level (I.L.) = 20 log $\dfrac{\text{rms intensity measured}}{\text{reference intensity}}$
(rms = root mean square)

RMS or root mean square is defined as the square root of squared values of sound pressure fluctuations (positive or negative) in air averaged over a sample time.

e.g.: in the case of a measured rms sound intensity of 0.26 (or 2.6×10^{-1}) watts/m^2, the intensity level in decibels re 10^{-12} watts/m^2 is equal to:

$$10 \log \frac{2.6 \times 10^{-1}}{10^{12}}$$

$$= 10 \log (2.6 \times 10^{11})$$

the log of (2.6×10^{11}) is 11.415, so the answer is:

10×11.415 or 114 dB to the nearest decibel.

This same result can also be achieved by the following mathematical procedure

$$10 \log (2.6 \times 10^{11})$$

$$= 10 \log 2.6 + 10 \log 10^{11}$$

$$= 20 (0.415 + 11)$$

$$= 114 \text{ dB to the nearest decibel}$$

However, it is fairly difficult to measure the intensity of a sound, and it is much easier to measure the sound wave's pressure fluctuations. This pressure is measured in pascals (Pa) (1 pascal 10^{-6} atmospheres). In order to double the energy, 4 times the sound pressure is required. Thus pressure increases at twice the rate that the intensity does. If we introduce a factor of 2 when we choose a reference sound pressure, the decibel value is the same for both.

	Sound Intensity	Sound Pressure
Quietest sound	10^{-12} watts/m^2	2 μ Pa

The definition of Sound Pressure Level in decibels now is written:

Sound Pressure Level (SPL) = 20 $\log_{10}$ $\dfrac{\text{rms pressure measured}}{\text{reference pressure}}$

(rms = root mean square)

Frequency

- Frequency is the physical characteristic of a sound that influences our perception of it as high or low in pitch. The audible frequency range is usually taken to be 20 to 20,000 Hertz (or cycles per second).

- Sound pressure level in decibels is not necessarily an indication of relative loudness of two sounds with different frequency contents.

Decibel (dB)

- A decibel is a logarithmic 'unit' that indicates the ratio between two powers. A ratio of 10 in power corresponds to a difference of 10 decibels.

dBA

- The very high and the very low sound frequencies are not heard by the human ear as well as the mid-frequencies are. This fact is incorporated into the standard sound level meter such that the 'A' weighting network on the meter gives the same response to the frequencies as the human ear does. Thus sound measured in decibels on the 'A-scale' (dBA) is considered to be a reasonably accurate approximation of noise levels as we hear them, and is known as the 'A'-weighted sound level or, sometimes, just "sound level".

Statistical Analysis of Sound L_5, L_{10}, L_{50}, Leq

- Sound can be statistically analyzed into L_5, L_{10}, L_{50} sound levels, These are the sound levels which are exceeded 5%, 10% and 50% of the time, usually in dBA.

- A sound can be statistically analyzed to find its energy average, or "equivalent sound level" as it is known, labelled Leq. This is the sound level of the continuous sound which would have the same sound energy as the actual time-varying sound over the period being considered.

- For highway noise, Leq sound levels are approximately 3 to 5 dBA less than L10 sound levels.

Mathematical Facts About dB

- When two sources of equal intensity are superimposed, an increase of 3dB results, e.g. 70 dB + 70 dB = 73 dB. This is due to the fact that when a number is doubled, its logarithm, to two decimals, goes up by 0.3. Thus, for example, in examining highway widening proposals, if the existing traffic volumes are doubled, the sound level would not double but would increase by about 32 dBA, all other factors being equal. For the addition of any two sources of unequal intensity see Figure 15.

- When the distance from a point source (e.g. a compresser, air conditioner) is doubled, an attenuation of 6.0 dB results, e.g. a sound level of 78 dBA at 15 meters would be 72 dBA at 30 meters. This is due to geometric spreading. That is, sound intensity varies as the inverse square of the distance from the source to the receiver.

- When the distance from an infinitely long line source, as in highway associated noise, is doubled, an attenuation of 3 dB results, e.g. a sound level of 78 dBA at 15 meters would be 75 dBA at 30 meters. The attenuation of 3 dB rather than 6 dB is due to the geometry of line source propagation.

  i.e.: cylindrical as opposed to spherical in the case of point source.

- Sound travels from a source in a radial manner.

  i.e.: from a point source it travels radially as towards the curved surface of a sphere.
  from a line source it travels radially as towards the curved surface of a cylinder.

- These figures for attenuation with distance doubling are approximate. Ground and air absorption tend to increase them by one to three dB. The figures also assume that no other sources contribute significally to the sound level. It should also be noted that distance attenuation differs for different statistical descriptors of the sound.

Subjective Facts About dBA

- A decrease of 10 dBA results in an approximate halving of the loudness experienced (loudness is the subjective magnitude of a sound).

  e.g.: 80 dBA is approximately twice as loud as 70 dBA
  60 dBA is half as loud as 70 dBA
  80 dBA is 4 times as loud as 60 dBA

- An increase or decrease of 3 - 5 dBA is normally regarded as just perceivable to a receiver.

- Figure 1 shows some typical examples of auditory response to different noise levels.

Figure 1

Auditory Response to Noise Levels

Sound Source	dBA	Human Response
	140	Painfully loud, heavy damage for any duration
	130	
Jet takeoff (61 meters) Auto horn (1 meter)	120	Exceedingly annoying
	110	
Jet takeoff (610 meters)	100	Very annoying
Heavy truck (15 meters)	90	Hearing damage (8 hours/day for a working career)
Upper decibel range for Ottawa Queensway, QEW and Hwy. 401	80	Annoying
	70	
Air conditioning unit (6 meters)	60	Telephone use difficult
Light auto traffic (15 meters)	50	
Living room	40	
Soft whisper (4.5 meters)	30	Very quiet
	20	
	10	Just audible
	0	Threshold of hearing

3.1.2 Some Basic Aspects of the Problem

Highway oriented noise problems and calculations are generally based on the noise coming from a line source rather than a point source and will be so considered herein. This in turn helps determine to what degree various attenuation measures are effective.

Notwithstanding, highway construction noise or noise emitted by single vehicles should be considered as originating from a point source.

When assessing a noise problem, there are three aspects which are considered:

1) the source
2) the receiver
3) the path between the source and the receiver

Source

Highway noise has three basic noise source variables:

a) the inherent noise producing ability of a travelling vehicle.

   - examples of this type are tire, engine, exhaust system and wind noise.
   - the Federal Government has passed legislation setting maximum sound levels to be met on the sale of new vehicles.

b) the operation of that vehicle on the roadway.

   - the Provincial Government has powers to pass legislation to control the maintenance and operation of vehicles once sold. Examples of noise due to bad maintenance are faulty mufflers and squealing brakes. Examples of noise due to inconsiderate operation are squealing tires and exhaust noise due to heavy acceleration.

c) the design of the road itself.

   - examples of this type are noise caused by tight curves in interchanges, short acceleration ramps, and rough pavement.
   - generally speaking, the higher the design standards, the less the opportunity for noise generated by tire squealing, noisy acceleration and brake screeching. Trade offs are necessary for such measures; rougher pavement may be safer than smooth pavement, an alignment utilizing steep grades may be less expensive than one utilizing low grades around a hill.

Receiver

While this Ministry has no jurisdiction over the receiver, it does submit comments to the Ministry of Municipal Affairs and Housing regarding the development of lands adjacent to Provincial Highways. This is aimed at discouraging residential construction within certain distances from the edge of R.O.W. depending upon noise levels generated and various factors dealing with cross-sectional geometrics or suggesting various land use measures, ranging from municipal zoning to subdivision plan configuration and building techniques.

The effects of traffic noise may include annoyance, interference with sleep, the performance of work, and speech communication. When complaints about existing or anticipated traffic noise are made, they should be treated with concern and sensitivity.

Path

This Ministry can make a major contribution to reducing noise problems through altering the noise path by:

a) locating the highways away from existing residential development and,

b) by depressing highways and utilizing berms or other barrier forms in noise problem areas.

However, locating the highway too far away from residential areas could reduce the accessibility and use of the highway and have the secondary noise impact of increasing the traffic volume on access roads and local arterials. Inadequate service provided on a highway could also cause overloading of local streets parallel to the highway thus worsening the noise condition rather than improving it.

3.2 Impacts

3.2.1 Identification of Noise Impacts

Many criteria can be used to assess noise impact and the noise environment can be described in many ways. To assist in an understanding of the processes used in establishing criteria, two such criteria are briefly described below:

1) interference with speech at a distance of six feet while outdoors. This reflects on human activity in general, though speech interference criteria are not the same as those for sleep, task performance etc.

2) the ambient sound levels which attempt to describe the existing conditions.

Speech Interference Considerations

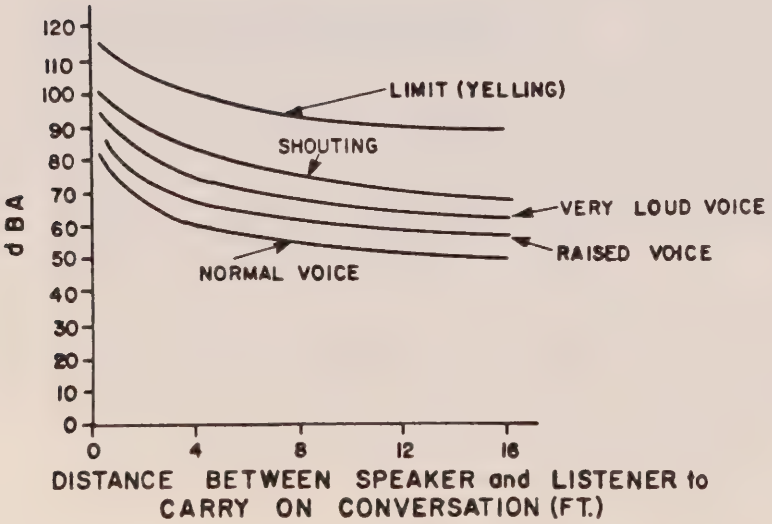
- researchers have tried to determine what minimum level of speech interference is acceptable for a given portion of the time.

- the basic approach here is to assure very good intelligibility for some minimum percentage of the time and to permit deterioration beyond marginal intelligibility for some smaller part of the time.

- the dBA levels causing various degrees of speech interference have been researched. The degree of speech interference resulting from various dBA levels is summarized in Figure 2.

Figure 2

Speech Interference



Ambient Sound Level Consideration

The ambient sound level is the all-encompassing sound associated with a given environment, being usually a composite of sounds from many sources near and far. It is usually measured in dBA and may be expressed, for example, in terms of L_{90}, L_{50}, or Leq.

Although it could be assumed that any increase in the ambient level could be expected to produce some type of reaction from the community, in fact, increases over the ambient sound level of up to 5 dBA may not be very significant.

Figures 3 and 4 illustrate sound level limits recommended by the Ministry of the Environment and the effects of increasing noise beyond these limits.

Typical ambient noise levels in terms of Leq, for night-time and day-time are:

30 - 45 dBA	-	rural
45 - 55 dBA	-	suburban
55 - 65 dBA	-	busy urban

A change in transportation associated variables such as number of lanes of traffic, volume of traffic or construction ofa highway where none existed before, will generally result in a change in ambient level. Therefore, it is essential that where changes in these variables are anticipated, "before" ambient levels be measured and recorded for future comparative purposes.

Figure 3

Sound Level Objectives for Outdoor Recreational Areas (in Leq)

Time Period	Sound Level Limit dBA
07:00 - 23:00 hours	55
23:00 - 07:00 hours	50

Figure 4

Effects of Increased Noise Levels

Excess Above Recommended Sound Level Objectives dBA	Change in Subjective Loudness Above Existing Level	Magnitude of the Noise Problem	Noise Control Measures (or action to be taken)
No excess	--	No expected noise problem	None
1 to 5 inclusive	Noticeably louder	Slight noise	Optional (if no physical measures are taken then prospective purchasers or tenants should be made aware by a clause in the deed or rental agreement.
6 to 10	Almost twice as loud	Definite noise problem	Recommended
11 to 15 inclusive	Almost three times louder	Serious noise problem	Strongly recommended
16 and over	Almost four times louder	Very serious noise problem	Strongly recommended (may be mandatory)

Ground and/or Air-Borne Vibrations

Among the factors which are sources of disturbance to people, particularly in urban areas, are traffic-induced vibrations in buildings. Although closely related to noise,vibration is not always distinguishable to the layman. Vibration may be directly experienced as an unpleasant sensation, and can further annoy people because of fears of possible damage to buildings.

Road traffic may induce building vibrations either by ground vibration originating from the interaction of moving vehicles with road surfaces irregularities or by low frequency sound emitted from vehicles. The low frequency sound can excite or rattle window panes, furniture, shelves, doors or similar loosely attached objects.

Traffic-induced vibration can be caused by several sources.

1. Irregularities in pavement profile,
2. Internal vehicle vibration,
3. Changes in roadway impedence, and
4. Infrasonic sound.

The most significant source of vibration is the passage of vehicles over irregularities of pavement profile, commonly resulting from expansion joints, manhole covers, differential settling of pavement slabs and potholes.

Internal vibrations of the vehicle from slightly out-of-balance forces are of secondary importance because of their higher frequencies and the efficient attenuation of modern suspension systems. Many other variations in the dynamic forces of vehicles due to acceleration and braking, tire stiffness and the negotiation of curves may also have an effect.

A dynamic disturbance is also generated by the motion of a steady vehicle load as it passes over changes in road impedence typically associated with bridges and culverts. This is because, although the induced force is independent of road impedence, the power transmitted into the roadbed increases as the road resistance decreases (and increases as the wheel impedence increases).

Finally, the exhaust pulse can transmit significant infrasonic sound to the soil or directly to the structures. The most apparent effect of the exhaust pulse is audible vibrations in windows and frames.

It has been found that ground vibrations are unlikely to cause perceptible structural vibrations in buildings located near to a well maintained and smooth road surface.

It can therefore be concluded that since irregularities in pavement profile are the most significant constributors to traffic induced vibration, the most effective abatement measure is to maintain the road surface in a good state of repair.

3.2.2 Determination of Noise Impacts

Highway noise can be characterized by three basic elements: the noise source, the transmission path and the receiver. Simply put, the noise produced at a source must travel along a path before impacting upon the receiver. However, the noise reaching the receiver is not of the same intensity as that produced at the source. This can be credited to certain attenuation factors which occur along the transmission path.

Noise levels at the source and/or receiver can be determined by two methods: measurement or calculation. Each method has advantages and limitations.

Future noise levels can only be determined by calculation while measurement is the only reliable method that can determine ambient noise levels at a site of a future highway (where traffic volume counts are non-existent).

Calculation of the ambient noise level along an existing highway will provide a more typical result (than would measurement) because of the benefit of traffic volume counts. In comparison, measurements provide an accurate representation of the noise levels at a given time, but this time may not reflect the typical condition. On the other hand, field sound measurements can include the effect of specific site features (such as ground and terrain attenuation and the presence of reflecting surfaces) which are difficult to include in calculations. It should be noted that a properly done measurement must provide better results than calculations.

However, measurements often are not as reliable as calculations. Many factors may affect the measurement, resulting in an unrealistic figure. For example, the measurement may be taken at a time when traffic is unusually low (or high), or wind or other noise sources are present. As a remedy, the noise levels recorded must be qualified to account for these influencing factors. This requires a traffic volume count and a documentation of other noise sources affecting the measured result, so that appropriate adjustments can be made.

3.2.3 Factors to Consider for Measurement or Prediction of Noise Levels

The four major factors which must be considered when measuring or predicting noise levels are:

1) volume of cars
2) volume of trucks
3) average speed of traffic
4) distance from source to receiver

1) Volume of Cars

For planning, site identification and prioritization, traffic conditions should be based on the higher of the Average Annual Daily Traffic volume or the Summer Average Daily Traffic volume. For design purposes, traffic volume shall be based on level of service C.

2) Volume of Trucks

The number of trucks is a critical factor, not only because trucks are usually a larger contributor to traffic noise than cars but also because it is more difficult to design highways to attenuate their noise (the exhaust outlet located near the top of trucks reduces the effectiveness of depressing the highway or of providing noise barriers).

3. Speed of Traffic

   As car or truck speed increases, greater noise is produced; therefore speed is an important parameter for predicting vehicle noise levels. An increase of approximately 1 dBA occurs for each 8 km/H. increase in speed. This is less significant for speed differences in the higher speed range than in the lower speed range.

4. Distance from Source to Receiver

   As sound energy propagates through air, a small part of the energy is converted into heat and is also dissipated by excitation of air molecules. The amount of sound energy that is absorbed in this manner is dependent upon the frequency of the sound and the temperature and humidity of the air. Attenuation by air absorption is very small; somewhere in the order of 0.002 dBA per meter. This insignificant cause of attenuation is often confused by the layman with "distance attenuation" where a significant reduction of noise is achieved due to the spreading of sound energy into larger and larger volumes.

   Theoretically, and not considering air absorption, distance is 6 dBA and 3 dBA per doubling of distance from the source for point sources and line sources respectively.

   The effects of atmospheric turbulence, wind, temperature and humidity gradients can cause considerable deviation from these values of distance attenuation. These effects will be discussed later.

   While the attenuation by distance results in a significant amount of attenuation to receivers close to the source, this amount of attenuation decreases as distance increases.

In addition to the reduction of sound by distance and air absorption, noise can also be attenuated by the effects of ground surface.

The amount of attenuation resulting from sound travelling over ground depend on the relative hardness of the surface, the distance between the source and the receiver, and the heights of the source and receiver above ground.

A hard surface, such as pavement, will reflect sound, not absorb it. As a result the resulting ground absorption would be nil.

A soft surface, such as grassland, will absorb a small amount of sound, which, when added to that attenuated by distance (3.0 dBA for line source) may result (for an incoherent line/source such as highway traffic), in a 4.5 dBA reduction per distance doubling.

To account for these effects the Ontario Highway Noise Prediction Method uses a 4.5 dBA reduction per doubling of distance from the edge of pavement to the receiver.

Other factors affecting the basic noise levels are:

5) grade of highway

6) elevation of highway and barriers

7) road surface

8) flow characteristic of traffic
   e.g. stop and go

9) continuity of line source
   e.g. interchange, variable profile

10) intervening structures
    e.g. rows of houses, townhouses

11) vegetation

The following mathematical adjustments are made to noise levels based on the Ontario Highway Noise Prediction Method (RR 197)

5) Grade of Highway

The noise of trucks increases significantly on an upgrade. Adjustments are made to the volume of trucks to compensate for the effect of grade. (Refer to Figure 12).

6) Elevation of Highway and Barriers

The sound attenuation due to highway features, such as cut and fill sections, is governed by the same relationships as sound attenuation due to barriers. Assuming a level terrain, large reductions of noise levels due to fill sections are obtained only for receivers at low heights above ground and the reductions decrease with distance from the highway.

If a highway is depressed, the noise attenuation increases as the distance from the highway increases. However, in order to be effective and to reduce highway noise, depressions of greater than 1.5 meters are needed to provide a benefit which is discernible; and to be substantially effective, depressions in the order of 6 meters should be considered since they can provide a benefit of 10 dBA (an apparent halving of the noise level). It should be noted that these benefits can also be obtained by material barriers or berm construction. The effectiveness of 3 meter high barriers was evaluated by the Ministry's Research Office and some of the results are in RR 180, "Noise Barrier Evaluation and Alternatives for Highway Noise Control". Additional investigations carried out by this Ministry into barriers since RR 180 was issued, indicate that 3 meter barriers can be more effective, depending on barrier site, than earlier Ministry experience.

7) Road Surface

If a moderately rough asphalt and concrete surface is considered normal, a smoother pavement would be quieter by about 2-3 dBA. A rougher pavement, e.g. a grooved concrete, would be noisier by up to 5 dBA. (Refer to Figure 13.)

8) Flow Characteristics of Traffic

The noise level near intersections is the logarithmic sum of the predicted noise level for each roadway. The noise level for each roadway is based on its particular characteristics, i.e. operating speed, volume, as well as stop and go adjustment.

For interrupted traffic flows, with truck volumes of at least 60 heavy trucks per hour, Leq sound levels should be increased by 2 to 3 dBA.

9) Continuity of Line Source

Adjustments to predicted sound levels should be made when the road is not a flat, straight road, of constant cross-section, carrying constant vehicle volumes. This would also apply at interchanges, and sections having variable profile, for example, depressed, at grade, or elevated. Where the road profile varies from at grade to cut, the noise level would be less than for a constant profile at grade. The adjustment factors for element size are described in the section "Ontario Highway Noise Prediction Method".

10) Intervening Structures

Any physical barrier, located in the sound transmission path between a source and receiver can provide noise reduction. Examples of barriers are, walls, berms, buildings, depressed roadways, and natural topographic relief.

The resulting attenuation varies greatly for each situation. To be most effective, the barrier must break the line-of-sight between the source and receiver and be continuous (i.e. without breaks which allow the leakage of sound).

The presence of other buildings between the roadway and the observer can provide a significant shielding effect for the first 2 or 3 rows of houses. A value of up to 4.5 dBA for the first row of houses or buildings and up to 1.5 dBA for each additional row (up to a maximum of 10 dBA) can be used. Therefore, the use of industrial or commercial buildings for such a sound buffer requires that they be designed to parallel the road with little open space between buildings. However, a solid row of townhouses would provide a more effective shielding and should be considered as a solid barrier with attenuation computed as such.

11) Vegetation

Attenuation by grass, shrubs or trees is highly variable, depending upon the nature of the ground surface, the type and structure of the vegetation, and the heights of the source and receiver above the ground.

Recent studies have concluded that vegetative buffer strips can provide some attentuation of noise. Unfortunately, however, relatively wide strips are necessary to provide a significant reduction.

In general, for distances from source to receiver of greater than 12 metres, forests provide better attenuation than do grassed lands.

In situations where the transmission path is interrupted by clumps of bushes, isolated trees or the intervening ground is covered with grass-like vegetation, an attenuation of 4.5 dB with doubling of distance can be expected.

In contrast, a forested strip of about 30 metres would be required to provide attenuation of about 10 dBA.

It can be expected that closed forests will provide better attenuation than would plantations where trees are planted in rows. Coniferous forests would provide better year-round attenuation than deciduous forests because of the presence of foliage throughout the various seasons.

The highway can be planned utilizing natural noise barriers such as hills and large, dense, mature treed areas. With trees that are 4.5 meters tall and sufficiently dense to eliminate the line of sight between the source and receiver, a noise reduction of up to a maximum of 10 dBA can be obtained per 30 meter depth of treed area. Since there are few residential areas capable of being buffered by such dense growth, there is little noise reduction possible using vegetation. However, it is recognized that landscaping can provide significant psychological improvement because of the visual screening of the highway.

In addition to those previously mentioned factors which can affect noise levels, the following factors should be considered:

- attenuation by atmospheric precipitation
- attenuation by surface water
- influence of atmospheric inhomogeneities and turbulence
- effects of stop lights.

12) Attenuation by Atmospheric Precipitation

When compared to the effects of atmospheric absorption previously discussed, atmospheric precipitation such as rain, snow, sleet, fog or dust causes only slight attenuation of sound. Because the attenuation resulting from atmospheric precipitation is relatively minor when compared to other effects, this factor can be ignored during a noise assessment. Notwithstanding, wet pavement will result in increased noise levels from traffic.

13) Attenuation by Surface Water

Generally water is considered as a hard surface, reflecting rather than absorbing noise.

Generally, for noise prediction purposes, attenuation due to water would be treated as 3 dBA per doubling of distance; the same as for air. A nomograph for the prediction for noise across water is provided in Figure 5.

14) Influence of Atmospheric Inhomogeneities and Turbulence

Sound waves are refracted by wind and temperature gradients which are ever present in the atmosphere. Air turbulence has the effect of scattering sound waves. The effects of atmospheric inhomogeneities can be quite large, ranging from 10 to 30 dB particularly for large distances between source and receiver. However, since these atmospheric conditions are constantly changing, it is virtually impossible to predict the resulting attenuation. Therefore, these conditions are not considered for highway noise prediction. Notwithstanding, air turbulence can increase noise levels by such means as rustling leaves and must be considered when measuring noise levels.

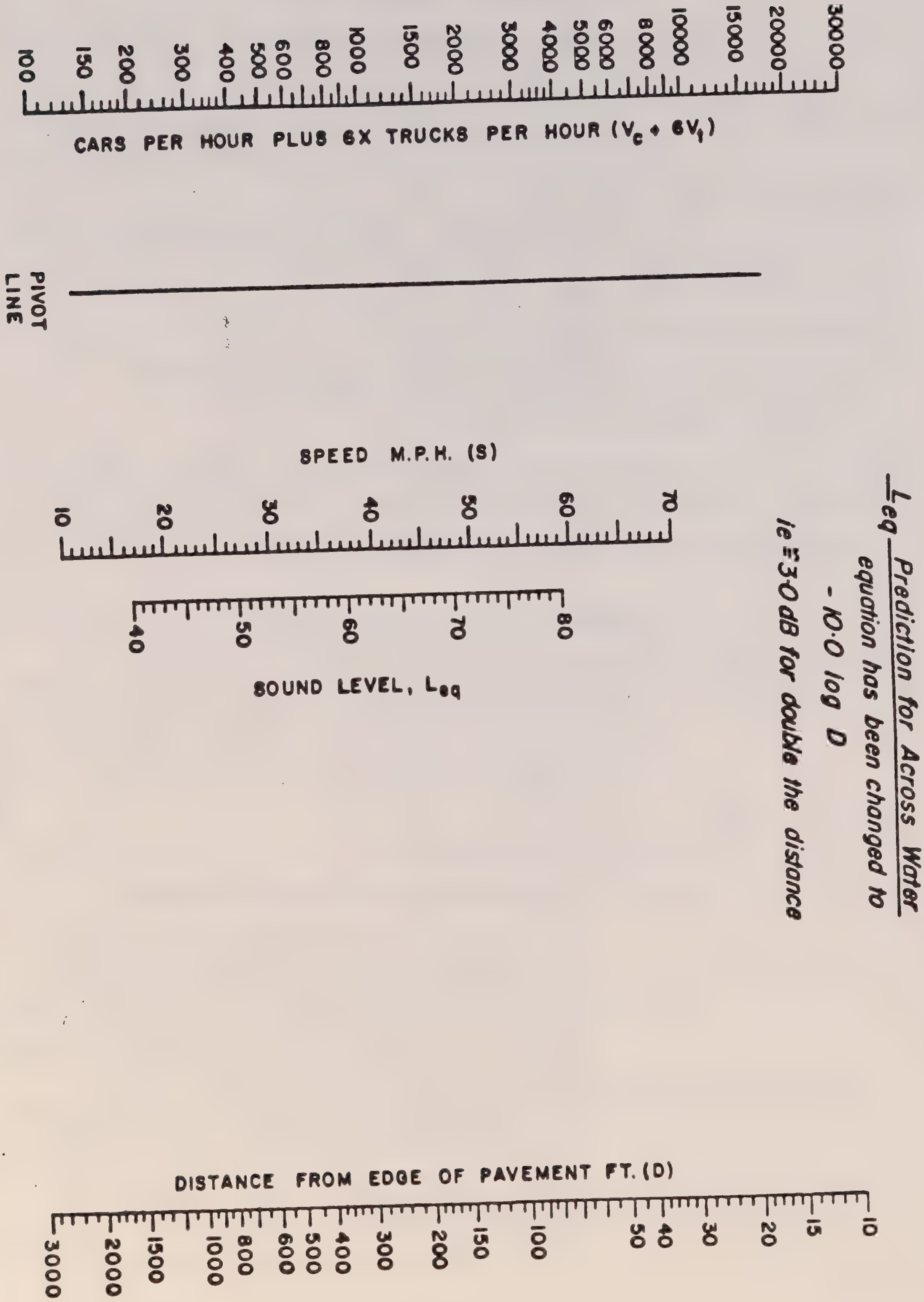
15) Effects of Stop Lights on Traffic Noise

The effects of stop and go traffic on a limited access freeway will not cause any increase in the "design" noise levels since traffic flows would be well below the noisiest condition; level of service "C".

However, on Provincial Highways where access is primarily from intersecting streets, stoplights may have an impact on the noise level emitted by a line of otherwise free-flowing traffic.

Figure 5

Leq Prediction for Noise Across Water



L_{eq} Prediction for Across Water equation has been changed to $-10.0 \log D$ ie ∓3.0 dB for double the distance

NOMOGRAPH FOR L_{eq} PREDICTION

In this case it may be necessary to determine the increase in noise levels although the construction of a noise barrier may not be practical for various reasons such as access, aesthetics, space, etc.

It should be noted that the effect of a traffic light is not necessarily the same as that of a stop sign. A traffic light will cause only a portion of the traffic to stop while a stop sign forces all of the traffic to stop. However, unlike a stoplight, a stop sign only affects a small percentage of the total traffic at any given time.

When evaluating the effects of traffic lights on noise levels, the following factors should be considered:

- traffic flows
- topography
- alignment and grade
- reflective surfaces (walls and buildings)
- absorptive surfaces (grassed slopes)
- pavement types.

Essentially, since traffic flows should be treated as free flowing traffic at the average operating speed (i.e. ignore the traffic lights), the noise prediction for situations with traffic lights should be the same as for those without traffic lights.

In other words, the effects of traffic lights should be ignored in noise prediction since the average noise level is similar to free flowing traffic, with the difference being greater extremes of high and low noise levels. These fluctuations should not vary by more (or less) than 5dBA from freeflow. Notwithstanding, the probability of perceiving higher noise levels, due to heavy trucks and peak noise occurences, should be recognized.

3.2.4 Prediction of Noise Levels

3.2.4.1 Ontario Highway Noise Prediction Method

The Ontario Highway Noise Prediction Method (RR 197) was developed in 1974 to replace existing noise prediction techniques with a method which would be more accurate and more applicable to the conditions of Ontario highways. The Ontario method of noise prediction is an imperical method based upon sound level measurements taken at various locations within Ontario. The equations and nomogrpahs were developed on the assumption that the highway was infinitely long, straight and level, with a continuous flow of traffic and no intervening structures. Adjustments to this ideal model accommodate the non-ideal characteristics of a real highway. The prediction method is therefore most appropriate for use on freeways and major two lane or multilane facilities. The method originally predicted L_5, L_{10}, and L_{50} sound levels, but has been extended to include Leq.

A) Limitations of the Ontario Method

The Ontario method tends to become inaccurate when extreme variations from the ideal condition occur. This situation arises when:

- vehicle flow is low in volume and intermittent (i.e. less than 200 v.p.h.)
- a high percentage of trucks occurs within the vehicle flow (i.e. greater than 20%)
- average speed of the vehicles becomes low (i.e. less than 30 m.p.h.)
- distance between the source and receiver becomes small (i.e. less than 50 feet)
- topography of the study area is very irregular (i.e. large areas of cut and fill adjacent)
- roadway has many ramps and curved sections (i.e. interchanges).

B) Use of the Ontario Method

The following variables are included in (or can be accounted for within) the Ontario method. These variables consist of:

A) volume of cars, V_c
B) volume of trucks, V_t
C) average speed, S
D) distance from source to receiver, D
E) intervening structures
  - artificial barriers
  - depressed/elevated sections
  - houses, buildings
  - vegetation
F) highway gradient
G) pavement surface texture
H) traffic flow characteristics
I) ground attenuation

The equations and nomographs developed in the Ontario method can be used directly to obtain sound levels if:

1) variables A to D are constant for a roadway section of approximately 8 D in length (D equals distance from source to receiver)

2) the last five variables (E to I) are not pertinent to the section of highway being assessed.

If conditions 1 and 2 are not applicable, adjustments must be made to accommodate these restrictions.

For land use activities adjacent to a major interchange area, the noise produced from the highway and intersecting roadway must be considered. The two roadways must be assessed independently to obtain their individual effect on the receiver. The noise produced by each roadway is then summed logarithmically to obtain the total impact on the receiver (the total impact should also include the effect of ambient levels). This method may also apply to major fly-overs and ramps.

C) Determination of Sound Level

Prior to the use of the equations or nomographs of the Ontario method, one must first determine certain preliminary conditions. The first point to be determined is which sound level is to be predicted, L_5, L_{10}, L_{50}, or Leq. L_5 sound levels tend to represent peak noise levels, giving an indication of the more objectionable levels of highway noise. The L_{10} and Leq levels provide an indication of the noisiest portion of highway traffic. The values of L_{50} are representative of near average or median noise levels. Leq is becoming accepted as the single descriptor of traffic and other noise which correlates best with the annoyance caused. A reliable prediction method has now been developed for Leq.

The use of the equations or nomographs should be restricted to sections (elements) of the highway which are approximately constant in terms of:

- car and truck flow
- traffic flow speed and characteristics
- pavement surface type
- highway gradient
- break in line of sight between the source and receiver.

The size of each highway section to be assessed is the longest section of highway for which these variables are constant. (Refer to Figure 9 for element size adjustment.)

D) Use of Equations

The equations for L_5, L_{10}, L_{50} and Leq of the Ontario model were formulated from an emprirical analysis of sound level recordings taken at various locations throughout the province. The following equations were developed.

L_5 - noise level exceeded 5% of the time
$= 56.5+11.1 \log_{10} (V_c+3V_t)-16 \log_{10} D+0.23S$

L_{10} - noise level exceeded 10% of the time
$= 52.7+11.2 \log_{10} (V_c+3V_t)-14.8 \log_{10} D+0.21S$

L_{50} - noise level exceeded 50% of the time
$= 30.4+14.5 \log_{10} (V_c+3V_t)-11.5 \log_{10} D+0.16S$

Leq - equivalent sound level
$= 49.5+10.2 \log_{10} (V_c+6V_t)-13.9 \log_{10} D+0.21S$

Where:

V_c = total volume of cars(GVW 10,000 lb.) veh./hour
V_t = total volume of trucks(GVW 10,000 lb.) veh./hour
D = distance from edge of pavement of first traffic lane to receiver, ft.
S = average speed of traffic flow, m.p.h. (average speed of all highway vehicles over a given section of highway during the time in question).

E) Use of Nomograph

In order to simplify hand calculations for sound level predictions, nomographs have been developed. It is suggested that the nomograph be used to forecast traffic sound levels and that adjustments are then made for the remaining variables, such as grade, elevation, etc.

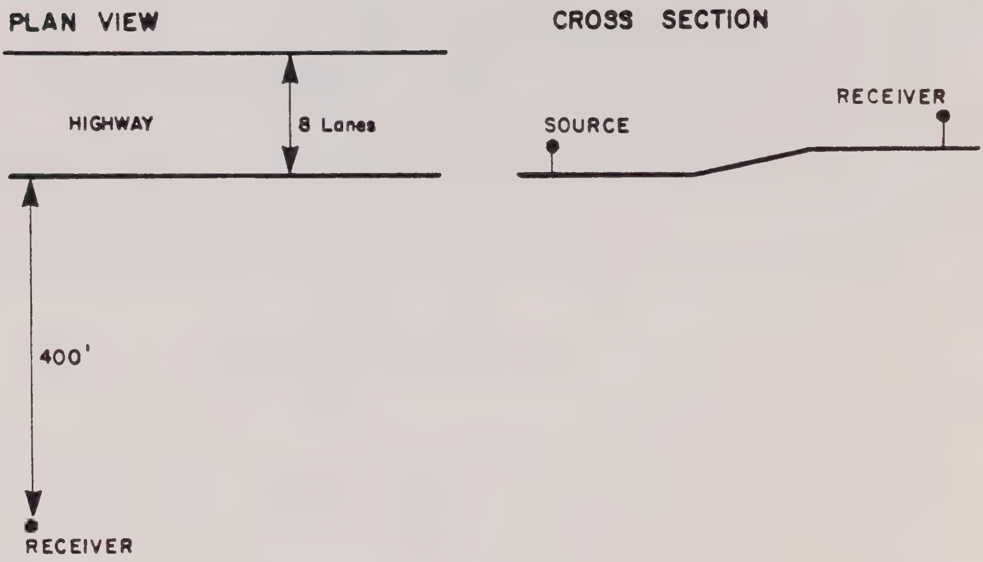
Example: Calculate Leq for the following situation:

- 6650 v.p.h. in both directions
- average speed 55 m.p.h.
- uninterrupted flow conditions
- 10% trucks
- 8 lanes of traffic
- 3% grade
- normal road surface

- distance from receiver to nearest edge of pavement is 400 feet
- there is a clear line of sight to the roadway.

Figure 6

Example Situation #1



Solution

Using the nomograph (Figure 7) with the variables of vehicles per hour, distance, percentage of trucks and average speed.

1. Calculate the volume of trucks

   Add the volume of cars plus 6x volume of trucks

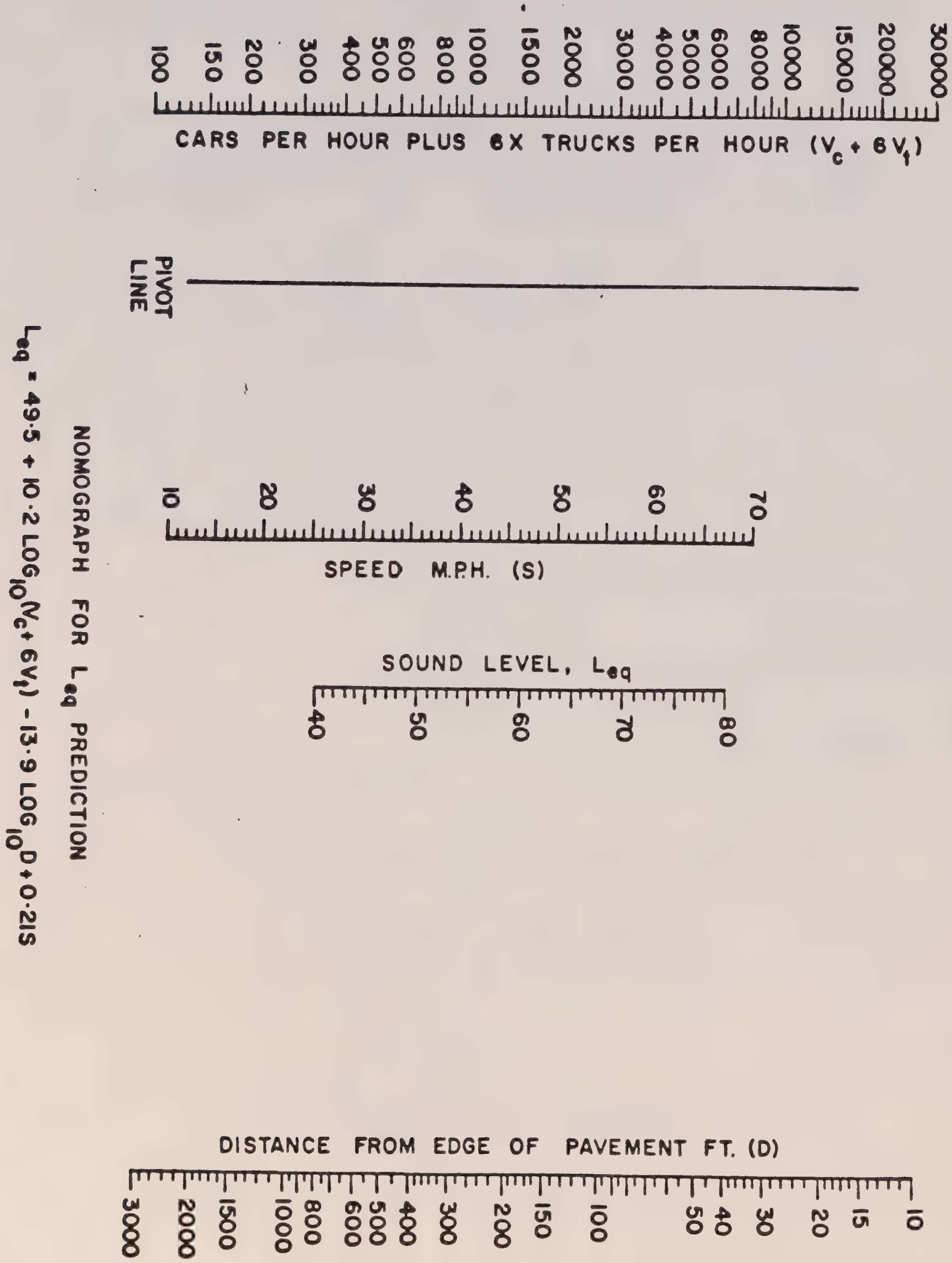
$$\begin{aligned} V_c + V_t &= (6650 - 665) + 6\ (665) \\ &= 5985 + 3990 \\ &= 9975 \text{ v.p.h.} \end{aligned}$$

Enter this figure on the left hand side of the nomograph, at point A.

2. Enter the average speed in miles per hour, at point B. Join points A and B with a straight line, and note where it intercepts the pivot line, at point C.

Figure 7

Nomograph For Leq Prediction



3. Enter the distance from edge of pavement to the receiver (400 ft.) on the right hand side of the nomograph, at point D. Join this point with a straight line to the intersection of Line AB (point C) on the pivot line, and note the intersection on the Leq sound level line, point E. This is the Leq sound level = 65.2 dBA.

For each section of highway under consideration, the following adjustments should be included, to accommodate for variations between the real roadway and the ideal roadway used as the basis of the model.

4. Adjustment for element size

   - Adjustments for element size are calculated using the following equation:

     ___ = 10 $\log_{10}$ $(\theta/180)$

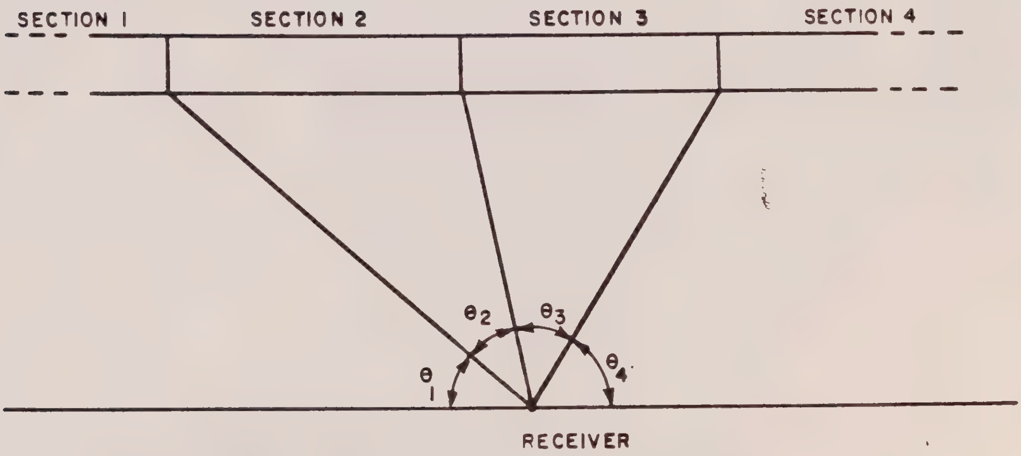
     Where:

     ___ = Adjustment for element size, in dBA

     θ = Angle at the position of the receiver, subtended by the highway section in degrees.

Figure 8

Element Size



- θ_2 = is the angle subtended by the highway section two.

- Adjustment for element size for various θ values can be obtained from the following table:

Figure 9

Adjustments for Element Size

Angle Subtended θ, Degrees	Adjustment dBA	Angle Subtended θ, Degrees	Adjustment dBA
180	0	35	- 7.1
160	- 0.5	30	- 7.8
140	- 1.1	25	- 8.6
120	- 1.8	20	- 9.5
100	- 2.6	15	-10.8
90	- 3.0	10	-12.6
80	- 3.5	5	-15.6
70	- 4.1		
60	- 4.8		
55	- 5.1		
50	- 5.6		
45	- 6.0		
40	- 6.5		

5. Adjustment for shielding effect of natural and artificial barriers

   - use Figure 8 for each highway element (refer to p. 3.3-6 for nomograph method)

   - determine the height of source from Figure 10.

Figure 10

Apparent Height of Source

Percentage Trucks (percent of total flow)	Apparent Height of Source (feet)*
1 or less	1
2	2
5	3
10	5
20	7
30 or greater	9

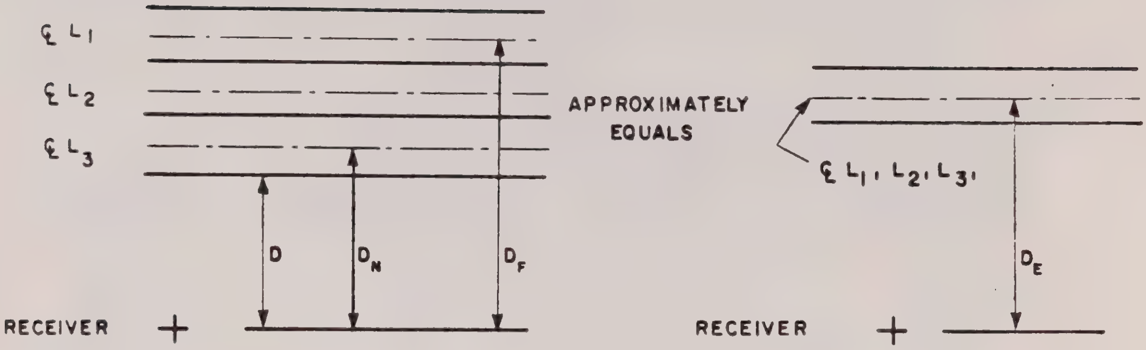
* 1 foot = 0·3048m

- Example: height of source 5 feet (for 10% trucks)
- determine the equivalent lane distance D_E

$$D_E = / D_N D_F$$

Figure 11

Example Situation #2



- Example:

  assume 12' lanes
  D_N = 400 + 6 = 406
  D_F = 406 + 2(12) = 430
  D_E = /406 x 430
  = 418 feet

- NOTE: - equivalent distances can be used only in the equations, the nomographs use distance from edge of pavement only.

  - Consider a cross-section of the highway and receiver, draw a line representing the direct line of sight between the source and the receiver. The height of the receiver is assumed to be 4' above the ground, unless 2nd storey windows are being considered.

6. Adjustment for highway gradient
   - no adjustment is made for cars
   - total vertical distance from the bottom of the grade to the top should be at least 20 to 25 feet.
   - use Figure 12 to obtain co-efficients to multiply truck volumes, to account for increase in truck noise on grades. This table is reproduced below:

Figure 12

Gradient Adjustment

Gradient %	Coefficient For Truck Volume Multiplication
≤2	1
3-4	1·5
5-6	2
≥7	3

- Example: have a 3% grade, which would correspond to a coefficient of 1.5 to be applied to V_t. However, the difference in total vertical distance is not known, therefore no adjustment is made in this case.

7. Adjustment for pavement surface type

   - use Figure 13 to obtain adjustment for surface type. Note that these numbers are typical for freeway traffic flow at 80 km/hr composed of 10 to 15% commercial vehicles.

Figure 13

Adjustment for Surface Type

Surface Type	Description	Adjustment (dB)
	Open Graded Friction Course	- 2.5
Increasingly Smooth	Dense Graded Friction Course	- 1.5
Normal	Asphalt Concrete HL1	0
Increasingly Rough	Asphalt Concrete HL3	+ 1
	New Portland Cement Concrete (Brush Finish)	+ 3.5
	New Portland Cement Concrete (Plastic Grooving)	+ 5.5

8. Adjustment for shielding due to vegetation

   - if tree spacing is dense so that no visual path between the source and receiver exists (does not hold for deciduous areas in the wintertime), and if the trees are at least 15 feet tall, apply a 5 dBA reduction per 100 feet of depth, up to a maximum of 10 dBA.

   - if the tree spacing is not as dense as above, and if the trees protrude above a barrier or berm, recognize that a small but unknown reduction will occur in the attenuation otherwise provided by the barrier or berm.

   - if the above conditions do not apply, assume no effect due to vegetation.

9. Adjustment for shielding effect of houses

   - obtain an approximate 4.5 dBA attenuation for the first row and 1.5 dBA attenuation for each additional row, up to a maximum of 10 dBA. (note: exact figures are not obtainable without a full description of the housing).

10) Adjustment for the effect of interrupted flow

- for intersections, traffic volumes and corresponding average speed for all intersection legs should be used for calculation of noise levels.

- L_{10} and L_{50} noise levels for interrupted traffic flows containing at least 60 heavy trucks per hour should be increased by 2 or 3 dBA.

11) Adjustment for ground attenuation

- the Ontario method may be used to forecast sound levels for receivers 4 feet above ground.

- studies have shown that sound levels increase with vertical distance above the ground level due to loss in ground attenuation.

- Figure 14 provides corrections to be applied for varying receiver heights.

Figure 14

Corrections in dBA Due to Ground Attenuation of Grassland

Height Above Ground (ft.)*	Distance From Edge of Pavement (ft.)*		
	100	200	300
4	0	0	0
10	+5	+4	+2
20	+7	+5	+3
40	+6	+4	+2

* 1 foot = 0·3048m

For each highway element the preceding adjustments are to be calculated (if applicable) and arithmetically added or subtracted to the predicted sound level. The adjusted sound level for each highway segment should be added logarithmically (if required) to obtain overall sound Levels. (Refer to Figure 15.)

Figure 15

Addition of Noise Sources

If dBA differ by	add to larger dBA	If dBA differ by	add to larger dBA
0.1	3.0	4.0	1.5
0.2	2.9	4.5	1.3
0.3	2.9	5.0	1.2
0.4	2.8	5.5	1.1
0.5	2.8	6.0	1.0
0.6	2.7	6.5	0.9
0.7	2.7	7.0	0.8
0.8	2.6	7.5	0.7
0.9	2.6	8.0	0.6
1.0	2.5	9.0	0.5
1.3	2.4	10.0	0.4
1.5	2.3	11.	0.3
1.7	2.2	12.	0.3
2.0	2.1	13.	0.2
2.5	1.9	14.	0.2
3.0	1.8	15.	0.1
3.5	1.6	20.	0.0

3.2.4.2 Canadian Mortgage and Housing Corporation Rail Noise Prediction Method

The Canadian Mortgage and Housing Corporation has developed a noise prediction method for train noise which involves the use of a series of tables rather than equations or nomographs.

The CMHC Rail Noise Model is included in its entirety in Appendix I. Also prepared by CMHC and included in Appendix I is a method for combining noise levels from various sources.

3.2.5 Measurement of Noise Levels

This section will provide a summary of basic principles for the design of noise surveys for transportation planning purposes and basic instructions to conduct these surveys.

However, due to the wide range of environmental variables, specific instructions cannot be provided for all situations.

3.2.5.1 Ambient Noise Measurements

The ambient noise in a given area is the total noise which is associated with and representative of a given environment and includes all natural and man-made noises from many sources both near and far. For comparison, background noise may be defined as the noise without a particular source in operation.

A proper understanding of what constitutes ambient noise is very important. The ambient noise measurements are taken to establish existing noise conditions. The knowledge of the existing noise conditions enables a comprehensive route evaluation and serves as a base for comparison with noise levels anticipated due to changes in the transportation networks.

In order to have a fair reference base for the existing conditions, a representative sample of ambient noise data must be taken. Care must be taken to exclude noises which should not be considered as part of the ambient.

3.2.5.2 Variables and Variations

The results of any ambient noise survey will be influenced by several variables.

The noise source is the most important variable. Sound level variation along major highways and expressways is about 5 dBA during daytime and about 10 dBA during 24 hours. Sound level variation along less travelled highways is about 50 to 100% greater.

A traffic count should be done precisely at the time of the measurement and be broken down by vehicle classification as follows:

- cars - all vehicles with two axles and 4 wheels
- light trucks - all vehicles with 2 axles and 6 wheels
- heavy trucks - all vehicles with 3 or more axles.

The distance from the noise source to the receiver will have an effect on attenuation. (The theoretical attenuation is 3 dBA and 6 dBA per doubling of distance for line sources and point sources respectively.) The distance above ground level may also affect noise levels.

The effects of weather must be accounted for. The propagation and attenuation of sound levels in the atmosphere is influenced by precipitation, wind velocity and wind gradients, temperature and its change with altitude, humidity, and atmospheric pressure in a number of ways. For example, quite moderate wind speeds may cause sound levels to fluctuate by ± 5 dBA over a few hundred feet from the source. Under certain conditions of wind and thermal gradients, ambient noise levels may be temporarily reduced or increased by as much as 10 - 15 dBA. For this reason it is recommended to conduct a few repeat ambient noise measurements at several locations, at one or two later-time periods (a few days or weeks later if possible).

Other weather related influences or ambient noise levels are leaves rustling in the wind, increased traffic noise due to wet pavements, increase in sound attenuation with distance due to soft snow cover, etc.

3.2.5.3 Selection of Noise Measurement Locations

All noise sources and noise sensitive locations should be identified using land use maps. Noise prediction methods for estimation of highway noise, railway noise, industrial noise, etc. should be used for preliminary estimation of the existing and future noise levels. The preliminary noise estimates are then used to:

a) identify areas or locations where noise impact is likely and where ambient noise measurements should be taken;

b) provide additional strength or verification to the field measurements by comparing measured values with estimated values.

3.2.5.4 Measurement Site Categories

All especially noise sensitive locations identified during the preliminary analysis should be studied separately. For most projects, it will be necessary to divide the study area into representative sections within which the existing noise environment can be typified by a single, or a few noise measurements. These sections should also correspond to sections for which the noise impact should be evaluated. Identification of sections and the location and number of measurement points within the sections will depend on the expected noise impact and the land use of the measurement site area. Typical categories of measurement site areas include:

a) Especially critical noise-sensitive sites such as schools, churches, hospitals,

b) Residential areas which can be further broken down according to:

  - present ambient noise levels
  - future noise levels
  - residential density

c) Sites near noise sources which will reflect the full impact of the noise source.

d) Remote areas which will represent the quietest regions.

3.2.5.5 Selection of Measurement Times

For the most meaningful comparisons of "before" and "after" noise conditions, both conditions should be determined for the same time period. This period is often a peak period or a period when design hour volumes occur since this period usually is used in noise impact guidelines. In other situations, the objective of environmental impact evaluation may be to assess changes in the existing noise levels during the whole day or, the critical period may be during the night. Ideally, a perponderance of ambient noise measurements should be taken during the most critical period.

3.2.5.6 Duration of Measurements

With the introduction of digital sound level metres noise level measurement has been greatly simplified. Measurement of sound over a given time period using digital instrumentation now is used primarily. Although digital instrumentation will provide instantaneous measurements, to record the most typical sound level, it is advisable to take the measurement for as long a time as is reasonable. A tape recording (analog measurement) is still required to analyze frequency in a lab or to replay for court purposes, etc.

3.2.5.7 Survey Design

Survey design includes identification of measurement locations, duration and time of measurements and the sequence in which the measurements should be conducted in the field.

General principles of survey design for ambient noise data acquisition are given below:

a) Randomization -

The sequence in which the measurements are conducted in the field should be randomized as much as possible.

b) Sequential Design -

If the study area is large, it may be advantageous to conduct the survey in two or more stages.

c) Variations of Error of Measurements -

Measurements should be repeated at certain locations several times to obtain some measure of the range of ambient noise levels under normal conditions.

d) Long Duration Measurements -

It may be useful to conduct one or two long-duration measurements (8 to 18 hrs.) within the study area to evaluate the change in noise levels during peak and off-peak periods and to determine how well this change is assessed by short duration measurements.

e) Practicability -

Although more intensive studies may be desirable, they may not be feasible or practical considering staff restraints.

3.2.5.8 Transportation Noise Measurements

Examples of transportation noise measurements are measurements designed to determine the change of noise levels due to highway widening or change in highway traffic speed, or measurements of noise levels emitted by individual vehicles. General principles suggested for conducting transportation noise measurements are given below:

a) Whenever possible, transportation noise measurements should take the form of statistically designed experiments.

The design may range from simple comparative experiments up to say, multivariable designs. A simple design might be the comparison of two locations while a multivariable design could involve the comparison of different factors such as seasons, day/night, week/weekend, or peak/off peak.

b) Whenever possible, the measurements should be conducted according to current or proposed CSA or ISO standards.

c) Special attention should be given to the selection of measurement locations. Reflective surfaces should not influence measurement results.

d) Unlike the ambient noise measurements, extraneous noises are always excluded from the transportation noise measurements.

3.2.5.9 Checklist for environmental analyst

The following step-by-step procedure is offered as a report summary for the analyst:

1. Identify objectives of noise studies; visit the study area if necessary.

2. Study land use maps and other pertinent documentation and estimate existing and future noise levels to identify the area where the noise measurements should be taken.

3. Select measurement sites according to measurement site categories. Specify locations where measurements should be taken at heights greater than 1.2 meters above ground.

4. Select measurement times to include both peak and off-peak periods.

5. Specify duration of measurements.

6. Identify locations which may require special measurement procedures and equipment. For example, certain industrial and construction noises should be measured using an impulse sound level meter.

7. Design the survey giving, for each location, time and duration of measurement and the suggested sequence of measurement. Specify which measurements are to be repeated.

8. Explain the survey design to field technicians. Explain what is considered ambient noise, i.e. which noises should be included and which should not. Specify a form in which survey results should be presented.

9. Evaluate and check survey results by comparing measured and calculated noise levels and by comparing measurements which have been repeated. Evaluate completeness of the survey.

10. Discuss the survey results with technicians; request more measurements if necessary.

3.3 Mitigation

3.3.1 Noise Reduction (Attenuation) Techniques

The problem of highway noise and its reduction should be the concern of several agencies, rather than one agency working independently. Parties to this concern are:

- Vehicle manufacturers, to produce quieter cars and trucks

- Tire manufacturers, to produce quieter tires

- Government agencies, to

    - develop and enforce noise controls
    - design transportation facilities that have minimal noise impact
    - Initiate research in noise abatement techniques

- Developers, to incorporate appropriate land use planning and home construction in areas adjacent to highways.

- Homeowners, to utilize adequate insulation, air conditioning and double glazed windows whenever desirable.

For example, the Leq noise level which can be expected from a 6-lane divided highway, at an offset of 60 metres (approximately centre of backyard of adjacent land use), is about 68 dBA. The Ministry of the Environment, as a result of their studies, is recommending:

Time	Level	Recommended (Outdoor) Maximum dBA
Day	Leq	55
Night	Leq	50

If it is assumed that the highway must be placed in an urban setting and that the land use adjacent to the highway is to be residential, then the noise impact of the highway will be 13 dBA above the recommended criteria. The use of barriers can only provide attenuation up to 10 dBA, the remaining 3 dBA can either be accepted by the residents of the area, or reduced by one of the methods previously described.

Within this Ministry the reduction of highway noise can be evaluated at the various stages of highway planning, design and construction. The factors to be considered are:

A) the highway relative to adjacent land use,
B) design standards and noise generation,
C) reduction of noise by barriers.
D) reflection of noise by barriers.

The first factor deals with minimizing the exposure to noise beyond the R.O.W. and could be applied at the route planning or preliminary design stage. The second factor involves design standards which may reduce noise levels caused by specific aspects of highway design. The third factor deals with the use of noise barriers to reduce the noise and visual intrusion of a highway. This measure should be evaluated during detailed design noise barrier costs are to be apportioned to the general construction costs of the project. This measure can be applied after construction although this may cause duplication of material and labour, as well as additional costs. The final factor explains problems with the reflection of noise from barriers.

A) The Highway Relative to Adjacent Land Use

Horizontal Location -

There are two approaches to reducing noise impacts on adjacent land use:

1) locate the facility away from noise sensitive areas.

2) control of land use adjacent to the highway by municipal zoning and development controls.

The appropriate development of land adjacent to a highway combined with barriers and landscaping can significantly reduce the severity of the noise impact.

Vertical Location -

The impact of noise on noise sensitive adjacent land uses can be reduced by depressing the highway. The placement of highways and interchanges in cut provides excess material which can be utilized to build barriers.

B) Design Standards and Noise Generation

The geometric design of the highway often affects the operation of vehicles on that roadway. In areas of dense residential land use, those design elements most likely to produce noise should be reviewed. Examples of traffic noise generated by highway geometrics are:

- tire pavement interaction
- upshifting and downshifting of gears
- prolonged use of lower gears
- stop and go situations (truck inspection stations, traffic signals).

Solutions to these problems to be evaluated during design are:

- maximization of:
    - radii for curves of ramps
    - lengths of acceleration and deceleration lanes
    - length of weave sections

- minimization of:
    - steep grades on interchange ramps
    - long grades

- locate "on ramps" on down grades and "off ramps" on up grades to improve acceleration and deceleration characteristics

- selection of appropriate pavement type

- avoid placing truck inspection stations adjacent to noise sensitive areas.

C) Reduction of Noise by Barriers

The use of barriers has been proven to be effective in the abatement of highway traffic noise under certain conditions. The effectiveness of these attenuation devices depends upon their design and location along the highway, and the evaluation of the area adjacent to the highway relative to it. These barriers may take the form of berms or noise walls. The cost/benefit of barriers must also be considered. Generally speaking, the greater the density of residences, the greater the benefit per unit cost.

In certain situations, such as rural areas, where extreme expenditures must be made to benefit very few residences, the application of such measures cannot be warranted.

Highway traffic noise can follow four main paths from source of receiver. These paths are:

- Direct Path - the traffic noise follows a line of sight to the receiver. If the barrier does not block this, no attenuation is provided by the barrier.

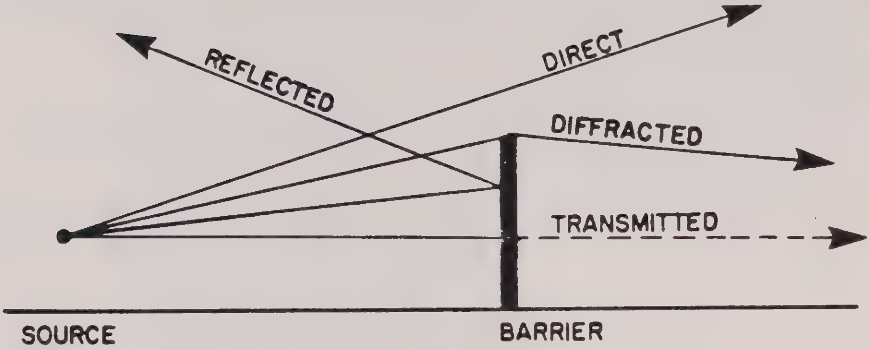
- Diffracted Path - This occurs for noise that passes just over the top edge of the barrier. The higher the barrier, and the closer it is to the source or receiver, the greater the attenuation it provides.

- Transmitted Path - The amount of noise transmitted through the barrier depends mainly upon the barrier density, and the number of openings in the barrier.

- Reflected Path - The amount of noise reflected by a barrier or other surface near the highway can be a concern to noise receivers on the opposite side of the roadway. Acoustical absorption on the face of the barrier will reduce this reflected noise, but it will not benefit any receivers behind the barrier.

Figure 16

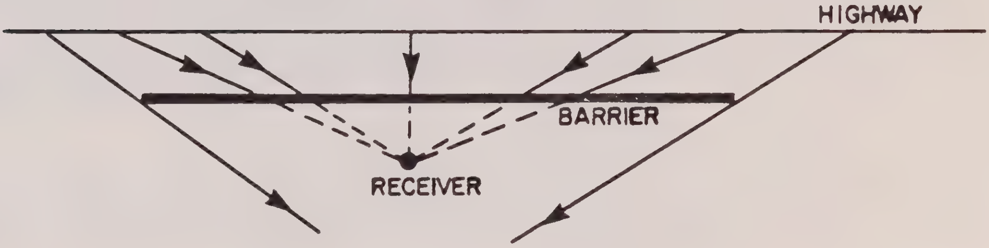
Reduction or Noise By Barriers



In order to be most effective, barriers must intersect the lines of sight to sections of the highway adjacent to the barrier as well as sections further up and down the highway.

Figure 17

Intersected Line of Sight



The reduction of noise by an attenuating device is dependent upon the amount of sound energy removed.

A reduction of 10 dBA requires the removal of 90% of the sound energy. A reduction of 20 dBA requires the removal of 99% of the sound energy. Therefore there is a practical limit to the amount of attenuation obtained by a barrier. In general, the following can be applied:

Barrier Attenuation

5 dBA - simple to obtain
10 dBA - can be obtained
15 dBA - very difficult to obtain
20 dBA - nearly impossible to obtain

D) Noise Reflection from Barriers

Reflection of noise from barriers may present a problem to residents on the opposite side of a highway to a noise barrier, or adjacent to parallel barriers. In both cases, as a result of noise reflected by the barriers, noise levels can actually be increased to a level greater than that experienced prior to the erection of the barrier.

The reflective characteristic of a barrier is dependent upon several factors including:

- The ability of the barrier material to absorb sound
- The size of the barrier
- Other reflective surfaces
- Overall geometry

The ability of barrier materials to absorb sound is qualified in terms of its absorption coefficient (α). This number can range between 0.0 (total reflection) and 1.0 (total absorption).

There are several different types of sound absorptive coefficients. The average of the absorptive coefficents is four octave bands (centered on 250, 500, 1000, and 2000 Hertz) and is known as the Noise Reduction Coefficient (N.R.C.).

The NRC for the various materials presently used for noise barrier construction in Ontario is approximately:

Durisol = 0.5 - 0.7
Evercrete = 0.1 - 0.4
Steel = 0.005

All other factors remaining equal, the greater the length and height of a barrier, the greater the amount of noise reflection that will occur. This can be explained simply by the greater amounts of noise striking the barrier.

To determine the amount of reflection by a barrier, factors other than the barrier size and materials must be considered.

The size, location and coefficient of absorption of other reflective surfaces such as exterior walls of apartment buildings must also be evaluated. The portion of noise reflected by the barrier which otherwise would have bounced off other reflective surfaces should be subtracted from the total noise reflected by the barrier.

In addition, the overall geometry of any situation must be considered. The distance from the reflected source to the receiver, the separation distance between parallel barriers, the profile of the highway, etc. all may be factors which affect the nature of reflected noise.

To minimize the effects of reflected noise, various mitigation measures can be used. The most apparent is the use of materials which are sound absorptive. Alterations of both barrier location (in relation to the source or receiver) and height can be considered. Barrier design to include such features as T-top, Y-top, or angled away from the source may also be possible to direct noise away from the receiver.

3.3.2 Determining Barrier Effectiveness

A. Barrier Nomograph Procedure (Reference (10))

The nomograph used to determine the attenuation of a proposed barrier design was developed on the assumption of an infinitely straight roadway with a barrier of uniform height that parallels the roadway at a constant offset. This condition is rarely obtained, and while the preceding assumption should be noted, it need not be stringently interpreted.

Prior to the use of the nomograph various physical parameters must be determined. From the cross-section drawings the following can be determined:

- Line of Sight Distance (L/S), is the slant distance (not the horizontal distance) from the source to the receiver.

- Barrier Break, is the distance along a perpendicular line from the line of sight to the top of the barrier. This distance is also referred to as the effective height of the barrier.

- Barrier Position, is the slant distance along the L/S from the barrier break point, to either the source or the observer (whichever is the shorter distance).

When using cross sectional drawings to obtain the preceding parameters, the vertical and horizontal scales should be identical. From the plan view drawings, the following parameter can be determined:

- Subtended Angle, is the angle subtended at the receiver by the ends of the barrier. The position of the receiver may be centred on the barrier, off-centre, at the end of the barrier, or beyond the end of the barrier.

The following example will illustrate the use of the nomograph procedure in determining the attenuation of a barrier.

Figure 18

Example #3: Plan View

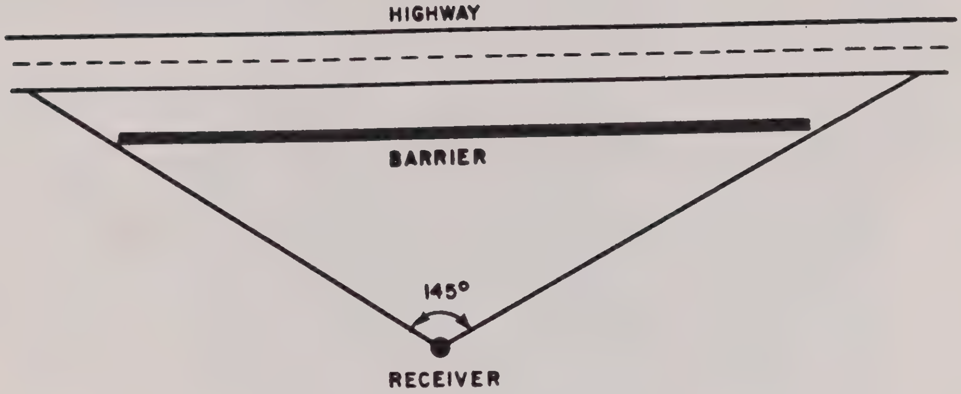
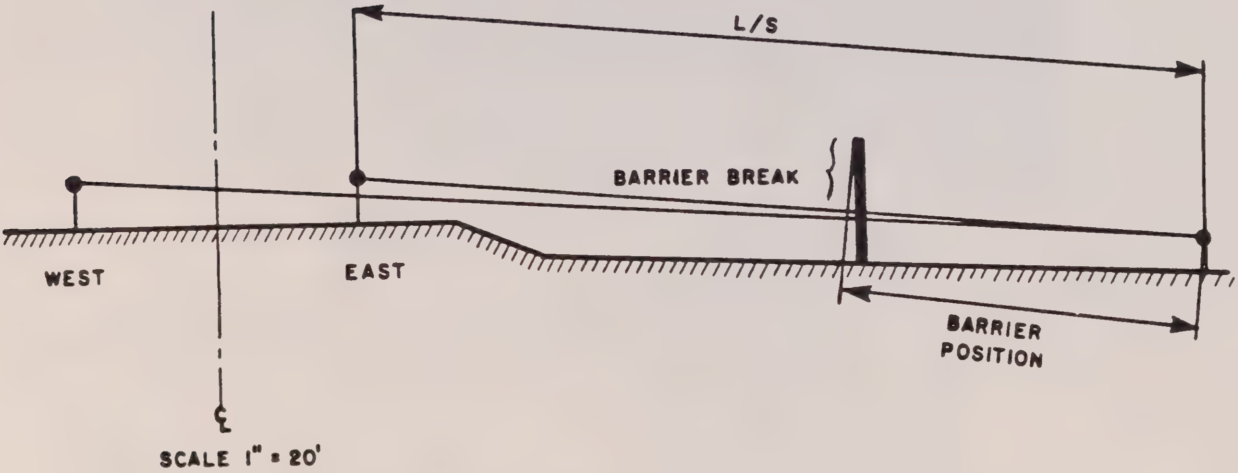


Figure 19

Example #3: Cross-Section



Given:
- Two 12-foot lanes each direction
- 15% trucks; apparent height of source - 6 feet
- 15 foot barrier
- height of receiver - 4 feet

Determination of Parameters:

- for the east lanes
  L/S = 103 feet
  Barrier Break = 9 feet
  Barrier Position = 43 feet
  Subtended Angle = 145°

- for the west lanes
  L/S = 137 feet
  Barrier Break = 10 feet
  Barrier Position = 43 feet
  Subtended Angle = 145°

These parameters are used in the following manner to determine the barrier attenuation (refer to the barrier nomograph, Figure 20).

> Starting at the bottom, left of the nomograph, a line is drawn from the L/S length, through the barrier position, to turning line A. From the point of contact on turning line A, project a vertical line. This line sets the position of the barrier relative to the source and receiver. Then, starting at the left of the nomograph, a line is drawn from the L/S length through the barrier break-in-L/S line to turning line B. Next, project this line horizontally into the attenuation curves until it intersects with the vertical line projected previously. The intersection of these two lines will lie on some particular barrier attenuation curve. This curve is followed upward to the right, to turning line C. From this point, a straight line is drawn to the L/S length at the centre of the nomograph. From where this line crosses the pivot line, a line is drawn horizontally to the right and reflected vertically upwards from the proper subtended angle line, to the barrier attenuation line.

Using the barrier nomograph (Figure 20), the following attentuation is determined:

- East Lanes, Attenuation = 7.5 dBA
- West Lanes, Attenuation = 7.5 dBA

Those attenuations are then deducted from the "no barrier" sound levels produced from the east and west lanes. The two sound levels are then summed to find the "with barrier" sound level at the receiver.

Points to Remember When Using the Nomograph:

a) The vertical and horizontal scales on the cross section drawings should be equal.

b) On a multi-lane roadway where traffic volumes have been concentrated into a reduced number of lanes, the noise source on the cross section drawings should be placed at the equivalent distance from the receiver. (i.e. an equivalent edge of pavement should be set.) (refer to Figure 11).

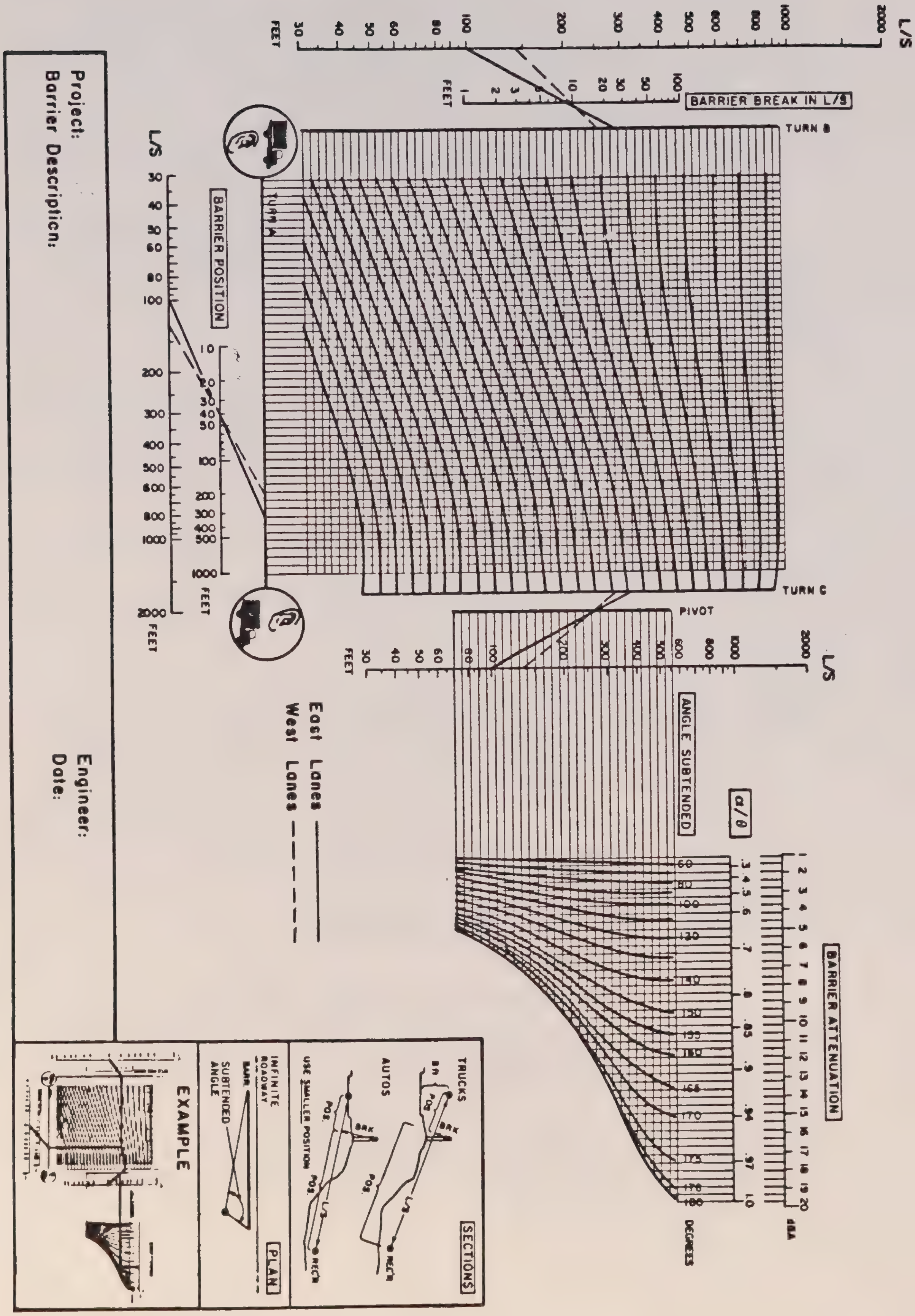
c) Always use the simplest line of sight (L/S) from the receiver perpendicular to the roadway. For depressed roadways always use the full L/S distance. The L/S is the slant distance not the horizontal distance.

d) The barrier break is measured perpendicular to the L/S.

e) The barrier position is the slant distance for the barrier to the source, and the slant distance from the barrier to the receiver. The distance used in the nomograph is the smaller of these two distances.

Figure 20

Barrier Nomograph



f) If the receiver is just at the end of the barrier the largest subtended angle possible is 90°, which results in a maximum attenuation of 3 dBA. For receivers beyond the end of the barrier the nomograph becomes inaccurate and should not be used.

g) If two or more barriers break the line of sight only the attenuation of the most effective barrier should be used.

h) Holes, openings or breaks in the continuity of the barrier cause a pressure doubling effect which tends to amplify the noise. Any discontinuity in the barrier should be avoided if possible.

Other Considerations

i) Transmission Loss (TL)

The transmission loss of a barrier is its resistance to the transmission of sound energy through the barrier. Therefore a high TL means less sound energy gets through the barrier. The transmission loss is dependent upon:

- wall weight (surface density, seldom exceeds 4 lb/ft^2)
- wall stiffness
- angle of incidence of approaching noise
- frequency of noise

j) Barrier Design

The use of a barrier of insufficient height may increase the annoyance of traffic noise. Barriers which are too small in height reduce the steady automobile noise, but have little effect on truck noise, the intermittent truck traffic noise becomes more predominant. This causes increased fluctuations of peak noise levels which may be more annoying than the conditions prior to the construction of the barrier.

3.3.3 Noise Barrier Site Identification

A. Retrofit

The Regions have identified candidate sites for the noise barrier retrofit program through observations by MTC personnel, analysis of maps and aerial photographs, existing and predicted noise levels, and by input from the public.

Although the listing of candidate sites for prioritization was essentially completed by the fall of 1977, additional sites have since been included where appropriate.

The priority list is updated annually to remove sites with barriers constructed and to account for new data which may affect the relative priorities (e.g. updated traffic volumes). Each Fall the priority list is reviewed to determine which sites are to be programmed for the following year. Sites are selected after considering the priority rating, political direction, and programming considerations, keeping in mind that the expenditure target Province-wide is $1 million per annum.

(i) Prioritization Formula

For the purposes of comparing one candidate noise barrier site with another, a Benefit/Cost ratio is computed by the Highway Design Office, for the proposed barrier at each site. The higher the B/C ratio, the higher a site will rank on the priority list.

The Benefit part of this ratio is derived by computer prediction of the existing noise level and barrier noise reduction at a large number of points of reception throughout the community, and is calculated as the product of barrier noise reduction and the amount by which the existing sound level is "excessive" (i.e.: above the objective noise level specified in Provincial Highways Directive B-94), summed for all homes at ground level.

The Cost part of the ratio is initially the dollar cost of the wall, calculated by the Highway Design Office for barriers of the same height. However, this cost figure is later supplemented by other costs expected to be incurred at a particular site, such as in placement of guide rail, attachment to New Jersey Barriers, etc.

Although computer calculations are used, the prioritization analysis should be seen as an evaluation package applied to a large number of sites to compare their suitability for barrier building on a common basis. The analysis is not intended to result in an optimum barrier design for a given site.

(ii) Technical Considerations

Past study has established that a barrier height of 4 m has the highest B/C ratio, and this barrier height among others is always included in the analysis. Past study has also established the barrier location in the Right-of-Way that gives the highest B/C; this is near the receiver for most terrain, near the shoulder for the elevated highway, and between the two if the terrain is elevated at the location of the barrier.

For the retrofit analysis, a 24 hour Leq is taken as the noise descriptor. The traffic volume shall be 1/24 of daily volume based on the higher of the Average Annual Daily Traffic or Summer Average Daily Traffic.

The points of reception assumed in the analysis are taken to be the outdoor "recreational area", 1.2 m above ground level, for each home at ground level. A typical recreational area is in the backyard approximately 3 m from the home.

B. New Construction/Reconstruction

Sites are identified for barrier construction in the planning process through observation by MTC personnel, existing and predicted noise levels, and through input from the public, ministries or agencies.

Noise control measures should satisfy the warrants of Provincial Highways Directive B-94, Provincial Roads Directives A-1, B-55 and C-16, and Municipal Transportation Roads Directive B-11.

In situations where a candidate site on the noise barrier retrofit priority listing is adjacent to a reconstruction project, every consideration should be given to including the barrier as part of that project. A grouping of the retrofit barrier project with a nearby roadwork project could result in the favourable unit price consideration as part of the road work contract.

C. Acoustical Design Advice

Regional staff usually request acoustical design advice through the Chairman of the Noise Barrier Design Liaison Committee. Requests for advice must be accompanied by the following:

(i) a site plan at a scale of 1:2400 (or larger) showing:

- contours or spot elevations of the pavement and outside recreational areas of the dwelling units.
- the dwelling units
- the number of residences in each unit
- the number of storeys in each unit
- the location or alternative locations of the proposed barrier.

(ii) traffic data for the main highway, interchange ramps, and major arterial roads adjacent to the site including:

- the 24-hour traffic volume (theoretical)

- the truck percentage
- the ratio of heavy trucks to light trucks
- the posted speed limit.

(iii) other factors which may affect the amount of noise or performance of the barrier including:

- length of barrier
- height of barrier
- material of barrier (if specified)
- single or parallel barrier
- other reflective surfaces
- pavement types
- natural and man-made barriers.

3.3.4 Landscape and Aesthetic Considerations in Barrier Design

To date, many noise barrier installations have sacrificed visual quality for acoustic "relief". This is understandable since barriers were justified primarily because of noise complaints, not visual pollution. Recently however, there has been an increasing public concern for aesthetics.

When designing a noise barrier application, there are several landscape elements which should be considered.

Material

The material used in noise barrier construction is perhaps the most important factor in aesthetics. Different products provide a range of textures, colours, post relief, etc., which, when carefully arranged can result in various pleasing effects. It should be noted however, that the predetermination of this effect is not always possible since the selection of the product to be used is usually left to the discretion of the contractor.

Notwithstanding, there are other landscaping principles which can also be used to affect the aesthetics.

Preservation of Existing Vegetation

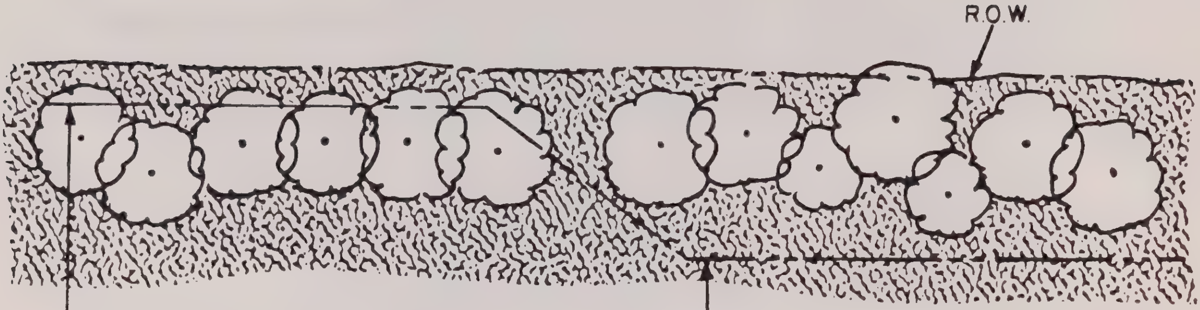
Location, species and condition of existing trees and shrubs should be determined in order to minimize removals and preserve plant materials wherever possible. Barrier installations should be performed around trees and not through them.

Improved Grade/Barrier Relationship

Improved relation to original ground and surrounding grades would result in a better fit rather than having a barrier that looks as though it is set on the ground. Contour grading on the design drawings can be used to blend barrier and original ground.

Figure 21

Treatment of Existing Fenceline Plantings



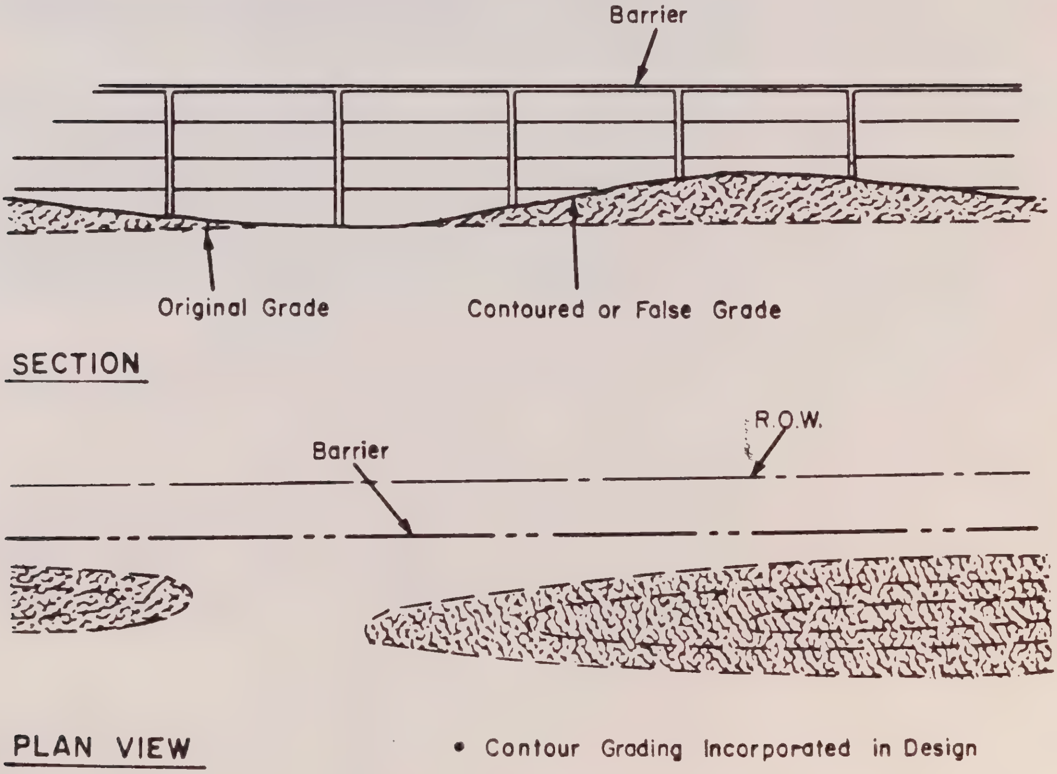
BARRIER BEHIND TREES
- pruning often required
- trees exposed to salt, dust, fumes
- visual benefit to motorist

TREE RELOCATION alternative to removal *if* size, species and condition are conducive

BARRIER IN FRONT OF TREES
- protected from hwy. intoxicants
- maintenance problem, that is, access
- visual benefits to residents

Figure 22

Grading Considerations



- Contour Grading Incorporated in Design

New Plantings

Plantings can be performed, where possible, around barriers to soften the linearity and monotony of line. Deciduous and coniferous trees in groupings will add the much needed variety to these installations. Funds for post construction planting are generally set up under sundry.

Termination Points

Termination of the barrier should be improved. Ends of noise barriers can be angled or tied back into structure approach fills, etc. Barriers should not dead end, but be tapered to fit the existing conditions.

Figure 23

Termination at Approach Fills

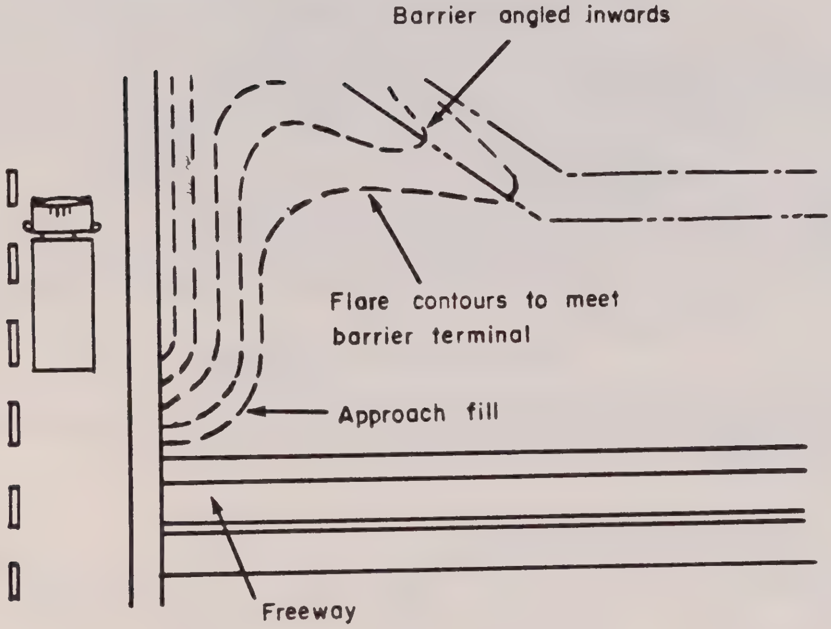
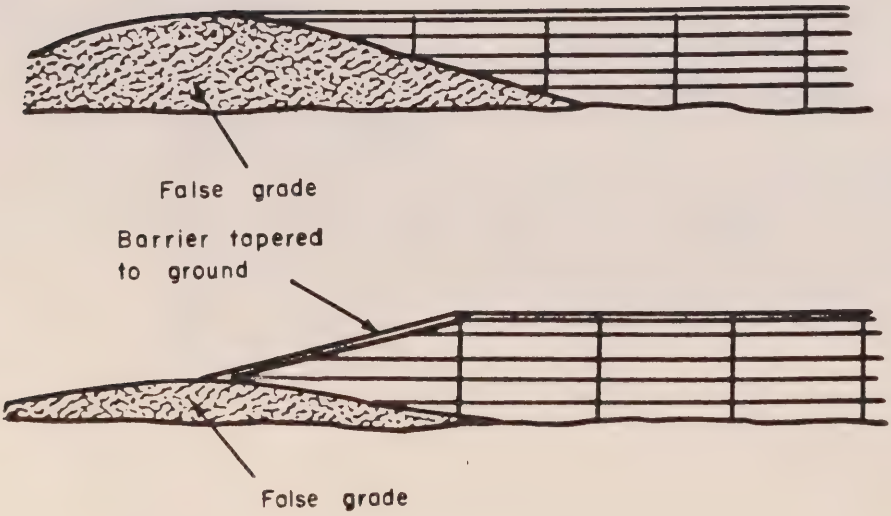


Figure 24

Termination at Open Ends

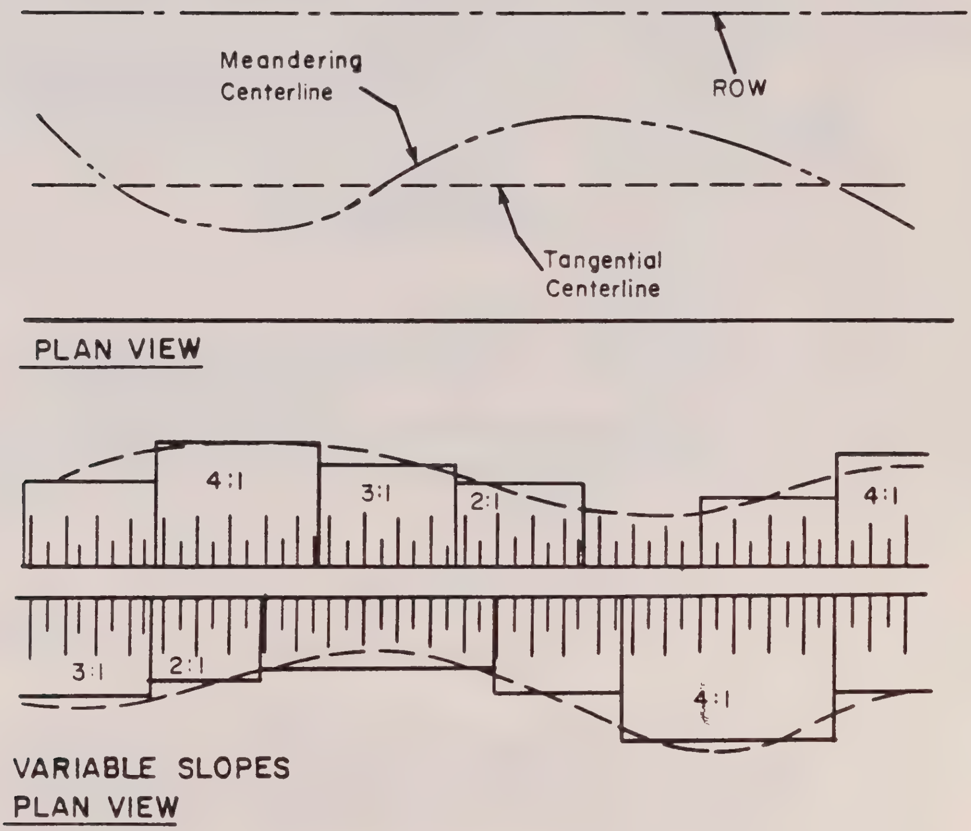


Earth Berms

Contour grading of earth barriers presents an additional possibility of providing landscape effect as an integral part of building the barrier without compromising the required acoustic relief.

Figure 25

Design Considerations to Relieve Visual Linearity



4. LEGISLATION AND POLICY CONSIDERATIONS

In the Province of Ontario, there are numerous legislative and policy considerations with which the environmental planner, designer, consultant, and construction personnel should be familiar when dealing with noise related to highway construction projects. For ease of reference, these have been divided into legislation, Government policy and MTC directives.

4.1 Legislation

4.1.1 Environmental Assessment Act

In general terms, this act requires the proponent of an undertaking to document the environmental impacts of the project and to describe methods to mitigate these impacts.

With respect to noise, this would involve an identification of sensitive areas, an understanding of how much noise levels will be increased above the existing ambient and an evaluation of where mitigation is required and what method should be used.

4.1.2 Environmental Protection Act

The Environmental Protection Act defines a contaminant to include both sound and vibration which have a negative impact on the environment.

This act makes provision for municipalities to pass by-laws regulating noise and vibration. The Ministry of Environment has prepared the Model Municipal Noise Control By-law, which among other things, suggests standards for construction and rural noise.

Where adopted by municipalities, such by-laws are binding upon both this Ministry and its contractors.

Where not adopted by a municipality, MOE may apply, as a condition of approval to a project, the standards of the Model bylaw.

4.2 Government Policy

4.2.1 Guidelines on Noise and New Residential Development Adjacent to Freeways

The main purpose of this guideline is to provide developers with an understanding of their responsibilities to provide noise mitigation where warranted. The guideline also establishes a provincial objective of 55 dBA and a noise level maximum of 70 dBA. The implications of this guideline to MTC have been fully defined in Provincial Roads Directive A-1.

4.3 Ministry of Transportation and Communications Directives

4.3.1. Provincial Roads Directive A-1

This directive entitled "Noise Policy and Acoustic Standards for Freeways" is an elaboration on the Provincial "Guidelines on Noise and New Residential Development Adjacent to Freeways".

The policy is divided into four sections; New and Expanding Freeways, Retrofit of Existing Freeways, New Residential Development Adjacent to Existing Freeways, and New Residential Development Adjacent to Planned Freeways. Each section contains warrants intended to determine where and when noise mitigation is required and who is responsible to provide it.

4.3.2 Provincial Roads Directive B-55

This directive entitled "Works Within the Right-of-Way by Developers" will provide direction in situations where a developer wishes to locate, in whole or in part, a noise barrier or berm within the MTC right-of-way.

Since this could result in potential problems in terms of barrier maintenance, grounds maintenance or access, reference to this directive and contact with the Corridor Control Section is required.

4.3.3 Provincial Roads Directive B-94

"Noise Control Measures for Freeways - Responsibilities and Design Consideration" outlines the responsibilities of the various offices involved in highway noise. This directive also provides design standards for noise control measures.

This directive will be useful in determining which office to contact for any given concern.

4.3.4 Provincial Roads Directive B-103

The Expropriations Act definition of injurious affection has been broadened to include personal and business damages resulting from construction. This, of course, can include noise generated from highway construction.

This directive, "Claims for Compensation for Personal and Business Losses During Construction", outlines a procedure which construction staff must follow prior to and during construction.

4.3.5 Provincial Roads Directive B-116

This directive deals with the subject of The Noise Barrier Technical Committee and the Noise Barrier Design Liaison Committee.

This directive establishes the two committees for consultant purposes. The Noise Barrier Technical Committee is intended to pull together inter-disciplinary expertise for developmental purposes.

The purpose of the Noise Barrier Design Liaison Committee is to provide a source of specialized advice and consultation for Regional designers in preparation of noise barrier contracts.

4.3.6 Provincial Roads Directive C-16

This directive on "Surface Course Mixes on Main Highways" provides direction on the use and application of open friction course mixes.

This mix is a "quiet" pavement and provides some attenuation of noise. It is generally used in urban areas, and where feasible, should be used in combination with other mitigation measures.

4.3.7 Municipal Transportation Roads Directive B-11

This directive deals with the subject of "Subsidy of Noise Control Measures on Municipal Roads".

This directive outlines the warrants that must be satisfied in order for municipalities to be eligible for subsidy for noise control measures.

5. PLANNING & DESIGN

The documentation in this section is taken primarily from the report entitled MTC - Environmental Assessment Report - "One Stage" Submission - Procedural Guideline 83-7 - Ministry of Environment.

In general, the focus of the E.A. documentation should be related to a significant increase above ambient noise on the selected route.

The E.A. should identify Environmentally Sensitive Areas which are defined as any noise sensitive areas (e.g. residential, institutional, commercial, or recreational) along the route of a project where the project may cause an "unacceptable" noise increase.

Noise matters on which the project team and the Noise Pollution Control Section of M.O.E. cannot arrive at a suitable agreement, should be passed on to the senior management of the two ministrires for resolution.

5.1 Route Planning Studies

5.1.1 Data Requirements

The purpose of doing a noise impact evaluation during a route planning study is to get an understanding of where the noise sensitive areas are located, and to what degree these would be impacted for each of the alternative routes being considered.

To this end it is necessary to identify noise sensitive land uses including residential, institutional, commercial, or recreational sites along each alternative route. To aid in this task, contacts with the Ministries of The Environment, Municipal Affairs and Housing and the local and regional municipalities may provide some necessary information. In an urban situation, there should be a systematic documentation of the noise impact for each route alternative, so that reviewers can ascertain that the recommended route has all negative aspects relative to noise identified. Ambient noise levels should be predicted and/or measured at various typical locations for each route alternative. In a rural situation, the evaluation could be less systematic, as the impacts of route alternatives would be similar. Predicted or measured ambients can be undertaken, although a "typical" rural ambient (30-45 dBA) will be sufficient in most cases. When the potential increase in noise level is required an actual ambient must be measured or predicted.

Following the establishment of ambient noise levels, the next step is to determine the noise levels after the introduction of the transportation facility. To predict this level, Provincial Highways Directive A-1 requires the use of the larger of AADT or SADT projected 10 years after completion.

For procedures for prediction or measurement of noise levels refer to sections 3.2.4 and 3.2.5 respectively. As the level of detail required for this planning stage is somewhat general, it is sufficient to use the nomograph procedure of the Ontario Highway Noise Prediction Method. (See section 3.2.4.1).

5.1.2 Analysis and Evaluation

For each of the alternative routes, after the noise sensitive land uses have been identified and their present and future noise levels determined, it will be necessary to analyse the data and evaluate the alternatives.

To aid both the planner in analysing the data and the reviewer in comprehending the information, it is necessary to prepare and present the data in the environmental assessment report in a reasonable way. The following information should be provided:

- A topographic map sheet(s) or an aerial mosaic(s) at an appropriate scale should be prepared showing the alternative routes, noise contours and all homes (as well as other noise sensitive land uses) affected by noise increases.

- A summary table showing the number of homes affected and the predicted noise level change at each should be prepared for each alternative route. A grouping of the number of homes susceptible to: 0 to 5 dBA, 5 to 10 dBA, 10 to 15 dBA and 15 dBA noise increases would be useful.

- for proposed new freeways through urban areas, a summary table showing the number of homes affected and the predicted noise level at each should be prepared for each alternative route. A grouping of the number of homes with predicted noise levels in the ranges of 55 dBA, 55 to 64 dBA, 65 to 69 dBA and 70 dBA would be useful.

In evaluating the degree of impact a noise level increase may have, it is useful to consult both the technical data (i.e. the decibel increase) and any feedback received by the affected residents during drop-in centres, etc. In some situations, public feedback will indicate serious concerns, while in other areas anticipated noise increases are not perceived as a concern at all. Both technical data and public feedback should be considered in determining whether or not the noise level increases are an "unacceptable" impact.

In addition to the negative impacts which must be addressed, any positive benefits which may be realized by implementing any route(s), should also be discussed. The comparison of positive and negative impacts will provide valuable input into the route selection process. The final route selected will of course depend on an evaluation of many factor areas, noise being only one; however resultant levels of 70 dBA and over (10 years after construction) should constitute an absolute constraint.

5.2 Preliminary Design

The documentation at this stage should build upon that done during the Route Planning stage, and follow the content and format requirements outlined in that section.

5.2.1 Data Requirement

The purpose of doing a noise impact study during the Preliminary design stage is to focus the analysis on the effects of noise level increases on the significant areas along the selected route.

During this stage, alternatives relating primarily to highway geometrics (horizontal and vertical alignments), intersection/interchange designs, etc., are evaluated. As such, more factors are available on which to base the noise impact assessment.

Significant areas, although identified in the planning stage for "A" projects, would need to be identified at the Preliminary Design stage for "B" projects. The same definition is used here as for Route Planning.

For "A" projects ambient noise levels will have been established in Route Planning. For "B" projects, ambients will need to be determined at this stage. The procedure is the same as that for Route Planning.

The degree of accuracy required for predicting future noise levels at this stage is greater than that for Route Planning. As such, it may be necessary to use the computer program of the Federal Highway Administration Noise Prediction Method or the manual hand calculation of the same using the equation and a calculator. This procedure will allow for the detailed evaluation of various factors such as topography, cuts and fills, alignment, and grade etc. which will affect noise levels. In cases where the topography is simple and it is apparent that the levels are below the range of impact, the nomograph method should suffice.

Noise predictions should include an assessment of each of the alternatives of the selected route relating to highway geometrics (horizontal and vertical alignments), intersection/interchange designs, etc., to determine which alternative(s) cause the least noise impacts.

5.2.2 Analysis and Evaluation

Following the identification of the significant areas along the selected route, and the determination of ambient and future noise levels, an analysis of the data and evaluation of the impacts is required.

To the extent possible, noise problems that have not been dealt with specifically during the Route Planning stages should be identified separately and an assessment of the potential impacts carried out to confirm that:

- there is a reasonable probability of the impacts occurring, and
- the impact and sensitivity are significant enough to warrant specific protective measures, or consideration of shifts in alignment.

5.3 Detailed Design

The documentation at this stage should build upon that done during the Route Planning and Preliminary Design stages, and follow the content and format requirements outlined in those sections.

5.3.1 Data Requirements

In the Detailed Design Stage, specific information on significant areas and noise impacts is studied to determine where the significant concerns are, whether mitigation is warranted and how that mitigation should be achieved in the most cost-effective manner.

The impacts upon significant areas have been determined in Preliminary Design. No further refinement of these are required at this stage, unless changes in profile, alignment, or cross-section are made that are likely to cause increases in noise levels.

5.3.2 Analysis and Evaluation

The need or justification for mitigation should be determined by evaluating the following:

- Provincial policy/legislation
- M.T.C. directives
- Request/requirements of review agencies
- External requests from municipalities, public, etc.

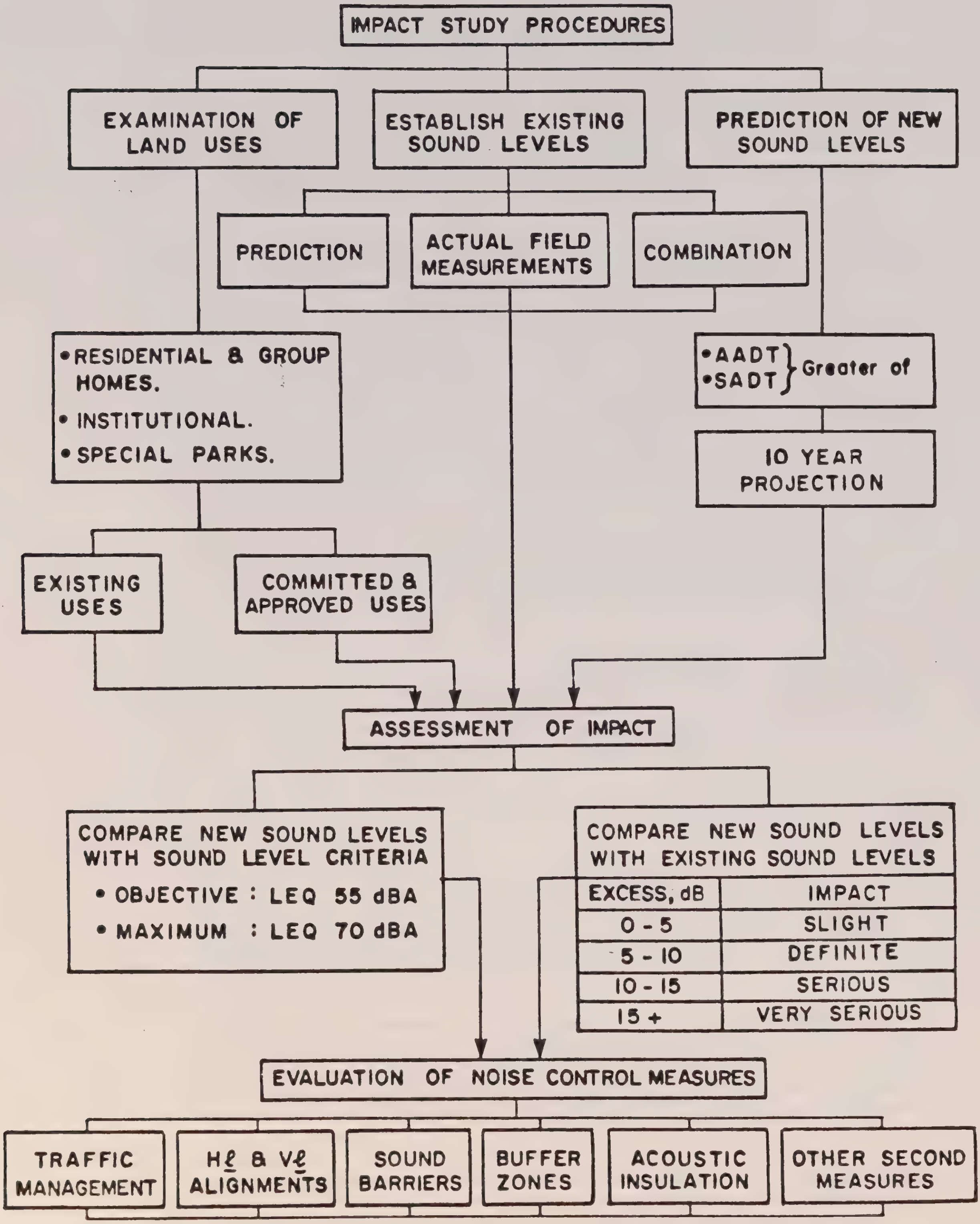
Once need has been established, it must be determined whether mitigation can be achieved in a cost/effective manner, and if so, which alternative mitigation method is the most cost-effective. To do this, the likely attenuation provided by each alternative mitigation method must be predicted. For berms and barriers this can be done by using the FHWA computer model or the barrier nomograph procedure of the Ontario Highway Noise Prediction Method.

Costs of applying the mitigation methods must be calculated and compared with the predicted attenuation to determine cost-effectiveness.

It is important to consider a "do nothing" option when comparing cost-effectiveness of different approaches.

Figure 26

A Flow Chart for Highway Noise Impact Assessment



EXCESS, dB	IMPACT
0 - 5	SLIGHT
5 - 10	DEFINITE
10 - 15	SERIOUS
15 +	VERY SERIOUS

6. CONSTRUCTION

In addition to noise generated by highway traffic, noise from construction activities and vibrations induced by road traffic are two major sources of disturbances to nearby residences.

Noise levels from construction equipment often exceed that of traffic noise. Diesel-powered pile drivers (100 dBA or greater at 15.2 m.), jackhammers (80 - 97 dBA), earth moving equipment (73 - 96 dBA), concrete mixers (75 - 90 dBA), and air compressors (70 - 80 dBA) are typical of the equipment to be found at the construction site.

Until recently, the general attitude of the public towards construction noise has been one of tolerance. Since construction noise has a short term impact at any one location, the public will tolerate it to a greater degree than noise from many other sources. Notwithstanding, the growing awareness of environmental noise and its adverse effects on man has led many municipalities and cities to pass noise control by-laws which establish acceptable noise limits and permitted hours of construction. In addition, Provincial Roads Directive B-103 recognizes that MTC may be liable for personal and business damages resulting from construction as per the Expropriation Act. This could include the effects of noise. As policy, Ministry Construction Staff must document the contractors operations which affect properties adjacent to the right-of-way on construction contracts.

At present, there are few methods used in Ontario to attenuate construction noise. Experiences of other jurisdictions (primarily Britain and U.S.A.) however, have shown that the technology does exist to permit significant attenuation.

Perhaps the most annoying source of construction noise is the pile driver. Correspondingly, many efforts have been made to quiet it. In a recent article by H.S. Gill in the Noise Control Engineering Journal of March-April 1983, the basic characteristics and noise levels produced by various types of pile drivers are explained. The following is an excerpt from this article.

> "There are many types of pile drivers. The most common categories are listed.
>
> **Impact Pile Drivers.** In the case of impact pile drivers, a regular sudden impact of a free piston or a weight on the top of a pile head is used to force the pile into the ground. The main types of impact pile drivers are the gravity drop hammer, diesel and pneumatic/steam.
>
> **Vibratory Pile Drivers.** The vibratory pile drivers perform best in granular soils or loose/medium density cohesionless soils, and are of limited use in heavy clay. Vibratory pile drivers are also used for pile extraction, but the pull on a crane attached to the top of the vibrator is required for the pile to be withdrawn from the ground.
>
> **Sonic Pile Drivers.** A more recent refinement to the vibratory pile driver is the resonant pile driver, in which the vibration excitation frequency is controlled to match that of a suitable longitudinal mode of the pile.

Augering Techniques for Pile Placement. The employment of various augering techniques for pile placement offers a quieter alternative to impact pile driving if the design and support requirements allow. After a pile has been positioned in the bore hole, concrete is poured into the base and the remainder filled with various mixtures of sand, cement and bentonite.

Miscellaneous Pile Driving Techniques. Electro-osmosis techniques may be employed sometime in the near future. This method is still in its early stages of development and has already been used to assist in pile extraction. DC electrical current is applied to the pile to activate the found water and thereby cause lubrication at the pile/soils interface. This method seems to be suitable only in clay soils and could have application in pile driving, although it is envisaged that problems could arise where pile interlocking is required.

Sometimes hollow core piles are driven with the internal drop hammer. Impact noise emanates near the bottom of the hollow pile section, which is under ground, after the first few hammer blows. Thus, there is some degree of sound attenuation and damping by the soil surrounding the hollow pile section.

"Quiet" Pile Drivers - Noise Reduction Techniques

In recent years there has been considerable progress in reducing noise from pile drivers. This section outlines the more successful noise reduction techniques employed to reduce noise from pile drivers.

Taywood "Pilemaster:" This is an electrically driven hydraulic pile driver which generates its driving force from frictional restraint of piles in the panel contained by the machine. The "Pilemaster" can be used for extracting as well as driving piles and is best suited to cohesive soil, because friction is essential to the driving process. Unlike most other systems, there is neither impact noise nor the generation of significant ground vibration from the "Pilemaster".

Dawson "Quiet Piling Rig:" The Dawson "Quiet Piling Rig" design is based upon the drop hammer principle. A steel jacket of 884 mm diameter encloses the cast iron hammer weighing 5 tons, and the anvil. Noise is attenuated by a specially constructed 125 mm dolly on top of the anvil, and by polystyrene chips which are fed to the impact surface through a 50 mm annular space between the hammer and the jacket, which serves to avoid metal-to-metal contact between the hammer and the anvil.

S.P.C. "Hush" Piling Rigs: Currently there are two main "Hush" systems in operation, namely the "Hush" gravity drop hammer and a "Hush" rig for use with a diesel hammer.

The "Hush" gravity drop hammer design is based upon the conventional drop hammer principle. The entire pile and the hammer assembly is enclosed in a large vertical rectangular box constructed from a a sandwich panel of steel and PVC rubber, giving an overall thickness of 16 mm. which effectively contains the noise. The composite wall is designed to reduce noise transmission in both mass and stiffness-controlled regions. The box has openings at the top through which the crane leads are passed and a door that consists of an entire front side. The pile is installed through the full length of the door, which is locked into position by large wing nuts. The box is made up of a number of sections (each with a door) to accommodate varying pile lengths. The bottom door contains an inspection hatch, which enables the operator to check progress during driving.

At present, the "Hush" diesel hammer employs a B225 Berminghammer to drive the pile(s) enclosed within a large vertical rectangular box whose construction is identical to the one used for the "Hush" gravity drop hammer.

DMD "4 Ton Solid 3N Initial Drive Hammer: this rig is based upon the drop hammer principle, employing a hammer weight of 4 tons. The hammer is not enclosed but is recessed on the underside. The hammer blow on top of the pile head is cushioned by introducing an asbestos padding material and "ship rope" between the pile head and the hammer.

Another version of the rig, namely the "5 Ton Solid 3N Drop Hammer," employs a hammer weight of 5 tons. This hammer has an additional one ton weight added at the top, otherwise it is identical to the "4 Ton Solid 3N Initial Drive Hammer."

Measured Noise Data and Discussion of Results

Figure 27 shows typical noise levels from "quiet" and conventional pile drivers at a distance of 15 metres.

Figure 27 places the piling and extracting rigs into three broad categories, according to noise levels emitted - "quiet", "semi-quiet" and "conventional" rigs. These categories allow a direct comparison of noise levels and assessment of the manufacturers success in reducing the noise levels in more general terms.

Examination of Table 26 indicates that the range of equivalent sound levels, Leq, measured within each category are 62 to 74 dB(A) for "quiet" rigs, 76 to 89 dB(A) for "semi-quiet" rigs and 93 to 106 dB(A) for conventional untreated rigs. These results indicate that the equivalent sound levels generated by extensively treated machines are approximately 20 to 40 dB(A) lower than those generated by untreated machines at equivalent distances, these reduced noise levels being equal to or less than that produced by other construction site noise sources. Generally, the expected equivalent sound levels generated by medium size conventional piling rigs at similar distances are in the range of 90 to 100 dB(A), and for larger capacity conventional piling rigs from 100 dB(A) upwards."

Figure 27

Measured Equivalent Sound Levels (Leq)

From Pile Drivers Driving Sheet Piles

Normalized To a Distance of 15 Metres

Item	Machine Type	Leq-dB(A)	Classification of Rig*
1	SPC "Hush" drop hammer	62-63	Q
2	Dawson "Quiet Piling Rig"	69-72	Q
3	Evans "Stealth Hammer"	81-83	SQ
4	DMD "4 Ton Solid 3N Initial Driver Hammer"	74	Q
5	DMD "5 Ton Solid 3N Drop Hammer"	82	SQ
6	DMD "6 Ton NAP Hammer"	81	SQ
7	"Sh-Sh-Shelbourne's Piling Rig"	79	SQ
8	Dawson "4 Ton Conventional Drop Hammer"	97	C
9	SPC "Hush" diesel hammer	71	Q
10	Delmag D60 diesel hammer	95	C
11	Delmag D30/02 diesel hammer	97	C
12	Kobe 35 diesel hammer	100	C
13	BSP B15 diesel hammer	85	SQ
14	BSP "Impulse Pile Driver"	87-89	SQ
15	BSP 700N pneumatic hammer	104-106	C
16	BSP HD& pneumatic extractor	93	C
17	Taywood "Pilemaster"	65-67	Q
18	Evans "Tomen Vibro VM2-5000"	81-86	SQ
19**	Hawker Siddeley "Resonant Driver Unit 400"	76-82	SQ

* Q = Quiet, SQ = Semi-Quiet, C = Conventional Machine
** Operated by Hawker Siddeley Canada Ltd., Vancouver, B.C.

Other Construction Equipment

As with pile drivers, efforts have been made to reduce noise output from other forms of construction equipment. Although information is not generally available for all equipment, data for jack hammers, compressors and crawler and track rock drills will serve as examples of attenuation which can be achieved with present technology.

Unsilenced pneumatic and hydraulically operated concrete breakers produce 84 and 79 dBA respectively.

In comparison, suited pneumatic and electrically operated concrete breakers produce 74 dBA.

An unsilenced compressor creates sound levels of about 79 dBA while a sound reduced compressor produces about 69 dBA.

Noise levels for unsilenced crawler and track rock drills range from 87 to 99 dBA. Exhaust mufflers alone could reduce this by 5 to 10 dBA.

Note all noise measurements above were measured at 15 metres distance from the source.

In addition to the preceding, there are several practical steps which can be taken to reduce noise levels or to mitigate their impacts.

Although several of these steps are not generally the responsibility of MTC, in exceptional circumstances and where sensitive issues dictate, MTC may elect to exercise jurisdiction.

1. Working Hour Limitation

   Noise impacts on adjacent land uses can be reduced by limiting the duration and hours of operation. Timing constraints, where necessary, can be included as a special provision of a contract.

   One drawback of using timing constraints can be reduced work productivity. Also, the noise impact will likely be spread out over greater periods of time. However, limiting construction during noise sensitive times of the day may be more acceptable.

2. Scheduling

   Separate activities can be undertaken at the same time with little increase in noise levels. This however may provide relief periods during the day when fewer activities are scheduled.

   Care must be taken to avoid situations where several combined activities produce "unacceptable" noise levels.

3. Off-site Hauling

   Haulage routes should be selected to avoid areas of high noise sensitivity whenever possible.

4. Barriers

   Where a permanent barrier is to be constructed as part of the overall construction, perhaps this could be erected during the early stages of construction where future work will not be affected.

   Temporary barriers are not normally considered as a method of attenuating construction noise. This is due to the fact that construction generates low frequency noise while barriers provide greatest attenuation to high frequency sound, thus resulting in insignificant attenuation.

5. Maintenance Scheduling

   Whenever possible maintenance activities should be carried out during working hours to avoid impacts, or adjacent noise sensitive sites.

6. Contact with Residents

   The project supervisor should notify residents of construction activities, scheduling, etc. Also construction office location and hours should be provided. Ministry staff should be available to handle complaints and answer questions.

7. Construction Equipment

   All equipment maintained in a good state of repair should satisfy noise level limits outlined in municipal noise control bylaws.

8. Municipal Noise Control Bylaws

Many municipalities have passed bylaws to control noise pollution. The contractor is responsible for being familiar with and meeting the requirements of any such bylaws in effect. The enforcement of such bylaws is the responsibility of the municipality.

Where no such bylaw exists, MOE may, through a condition of approval of an E.A., apply the model municipal noise control bylaw. In such cases enforcement is the responsibility of MOE.

7. MAINTENANCE AND OPERATION

The following points should be considered during design, to ensure that additional maintenance, as the result of noise barrier construction, is kept to a minimum.

i) Discuss design with maintenance staff.

ii) Locate noise barrier to facilitate access for equipment behind barrier for grass cutting and weed spraying.

iii) Maintain accessibility for fence repair, litter pickup, etc.

iv) Locate barrier to avoid shading of roadway and shoulder for Winter maintenance ice control.

v) Locate barrier to provide snow storage behind curb.

vi) Avoid gaps in barrier which might create snow drift problems

vii) Locate the barrier as far from the shoulder as possible to provide optimum space for snow storage and to eliminate the need for hand removal of Winter sand at flexrail. If guide rail is required, posts at 6-foot centre should be adequate.

viii) If earth berms are built, the slopes should not exceed 3:1 for ease of mowing.

8. MONITORING

Monitoring of noise problems and noise mitigation methods is useful to gain an overall understanding of general concerns as well as specific knowledge of any given situation.

Information from monitoring may be of benefit in the following areas:

- Public opinion
- Barrier effectiveness
- Other concerns

Public opinion is a valuable planning tool in determining need for and acceptance of noise mitigation methods. Often, concerns of noise impacts are not raised although technical data would indicate that there will be a significant noise level increase. Conversely, concerns can be expressed over sound quality changes even when levels are not increased significantly. Generally, in urban areas noise barriers are accepted and requested. In rural areas residents may find visual barriers more offensive than the noise itself.

Over the past decade, MTC has undertaken several public surveys to gain a better understanding of public opinion with respect to highway noise and noise barriers.

Barrier effectiveness can be determined by carrying out public surveys and by undertaking before and after (application of mitigation method) noise level measurements. The information gathered by such monitoring is valuable to assess the accuracy of noise predictions, especially in unfamiliar situations.

Monitoring can also be valuable in determining the effectiveness of various barrier materials. Information can be gained to determine which materials are most sound absorbent, least costly, have the greatest longevity, require the least maintenance, etc. This data is valuable in determining cost effectiveness.

Other concerns which should be monitored are secondary factors such as increased privacy, reduced salt and dust, decreased safety from icing, shadows, claustrophobial effects, snow removal and a host of other similar concerns.

Monitoring may not be required in most situations. However, when a new problem is encountered, the Environmental Office and Regional Environmental Units should be contacted so that a monitoring procedure can be developed and implemented so that the benefit of knowledge gained can be applied to similar situations in the future.

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10. APPENDIX I

CANADIAN MORTGAGE AND HOUSING CORPORATION RAIL NOISE PREDICTION METHOD - RAIL TRAFFIC NOISE

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SECTION A - RAIL TRAFFIC NOISE

Introduction

A comparison might be attempted of the effects of highway noise and railway noise, because both have equally high noise levels. However, the similarity ends there since railway noise consists generally of a series of separate events, all similar in character, whereas highway noise is more continuous, though with random fluctuations.

The noise generated by railway trains is associated with three sources -- the engine, the whistle and the interaction of the wheels and the rails. Because the propagation of noise from these sources is quite different, the noise which each generates at the site must be evaluated separately. The contributions from the three components of railway noise are combined by the procedure given in Part 5.

Cautionary Note

Caution should be exercised when building within 100 m of a railway line. At these distances there is a possibility of high vibration levels within the building due to both ground vibration and airborne noise. In situations such as this, it is recommended that heavyweight construction be used and that a qualified person be consulted about other forms of vibration control which may be necessary.

Main Sources of Noise

There are three major sources of noise from railway rolling stock: the locomotive-engine noise, the movement of the wheels over the tracks, and the audible warning whistle device. Again there are a number of factors directly affecting the amount of noise an individual hears:

- Train Composition - the number of locomotives and railway cars in a train affect both the engine and the wheel-rail noise.

- Track Condition - long, smooth, welded rails are quieter than short rails with open expansion joints. However, guidelines assume that the latter are used.

- Train Speed - as the speed increases, so does the engine and wheel-rail noise. Changes in speed alter the duration of whistle noise.

SECTION B - PREDICTION OF OUTDOOR NOISE FROM RAIL TRAFFIC

This section outlines a procedure for taking account of the variables discussed in Part 4, Section A.

Step 1 - Traffic Characteristics

To determine the noise level generated by the locomotive engine and train wheels, the following information about a site is required and is available from a railway operations officer.

1. Nominal train speed in kilometers per hour.
2. Total number of locomotives in 24 hours.

   Note: A self-powered rail car shall be counted as one locomotive if diesel-powered, or as two railway cars if electrically powered.

3. Total number of railway cars in 24 hours.
4. Total number of whistle points (if any) within 750 m of the site.

Step 2 - Calculation of Engine Noise

To calculate the noise emitted by a railway locomotive requires the average train speed and the average number of railway cars pulled by each locomotive. The latter is obtained by dividing the number of cars by the number of locomotives for the 24-hour period.

The noise level at a distance of 30 m from the railway centreline for a train speed of 80 km/h is then obtained from Table 4.1.

Table 4.2 gives the corrections to be added to this value to obtain the noise level for other train speeds.

For horizontal distances other than 30 m, the procedures of Step 4 are used, for propagation over "hard" or "soft" ground as the case may be. For locomotive noise, the source height is taken to be 4 m above the track.

The noise from railway locomotives may be reduced by the presence of an obstruction that interrupts the line of sight between the engine and the observation point. calculate the barrier attenuation, following the procedure of Step 5, using a source height of 4 m above the track.

Step 3 - Calculation of Wheel-Rail Noise

Obtain the wheel-rail noise level at a point 30 m from the track centreline from Table 4.3, using the train speed and the number of cars obtained in Step 1.

For horizontal distances other than 30 m, the procedures of Step 4 are used, for propagation over "hard" or "soft" ground as the case may be. For wheel-rail noise, the source height is taken to be 0.5 m above the track.

If the line of sight between the source and the observation point is interrupted, calculate the barrier attenuation, following the procedure of Step 5 with the source height 0.5 m above the track.

Step 4 - Correction for Distance

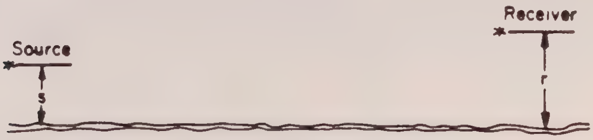
The procedure up to Step 4 gives the noise levels for a receiving point 30 m from the centreline of the track, when the ground surface is hard. If the receiver position or the ground surface are different from this, the noise level may be higher or lower. In general, the noise level diminishes as the distance between source and receiver is increased.

An accoustically "hard" surface is one that reflects sound well. This would include such surfaces as concrete, asphalt, clay or compacted gravel. If more than half the ground surface between the source and receiver is "hard", the distance correction should be calculated, using the section of Table 4.4 for "hard" ground.

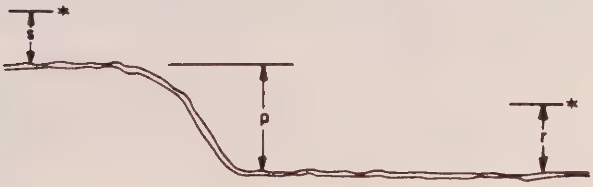
Because the distance from the source to a receiving point above or below source height is greater than the horizontal distance, lower outdoor noise levels would be expected at the upper storeys of a multi-floor building than at road level. However this reducton in outdoor noise levels is offset by dependence of the building's noise insulation on the angle from which sound arrives. For this reason, the distance correction is based only on the horizontal distance if the ground surface is "hard".

If more than half the surface between the source and receiver is "soft" (e.g., planted with grass, shrubbery or other dense vegetation) an extra reduction in the noise will occur if the path of the sound from source to receiver is near the ground. The height of the source and receiver above the ground and the height of any intervening barrier affect the noise reduction associated with a soft surface. An "effective total height" must be calculated from the heights mentioned above, using the expression given in the appropriate diagrams in Fig. 4a. then, using this effective total height and the horizontal distance, obtain the distance correction from the section of Table 4.4 for "soft" ground surface.

Fig. 4a Effective total height above ground

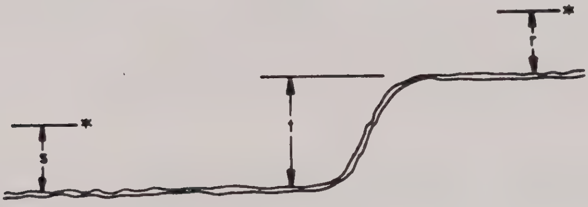


No barrier-effective total height=s+r

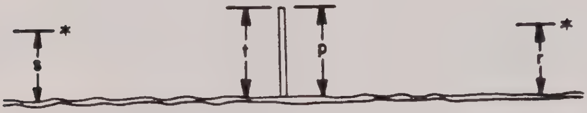


Effective total height=s+p+r

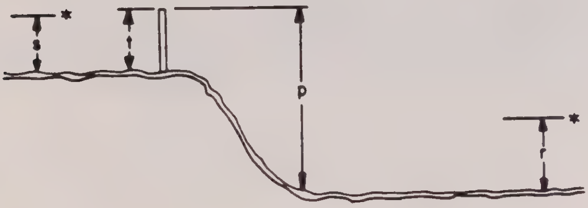
Fig. 4a Effective total height above ground - (cont'd)



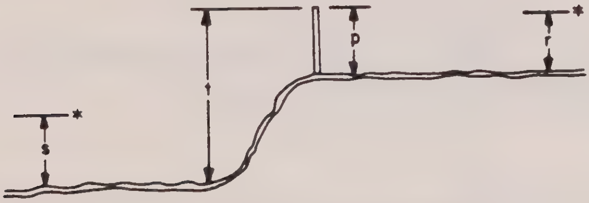
Effective total height=s+t+r



With barrier-effective total height=s+t+p+r



With barrier (depressed site)-effective total height=s+t+p+r



With barrier (depressed road)-effective total height=s+t+p+r

Step 5 - Correction for Barriers

The noise from railways may be reduced by the presence of any obstruction that interrupts the line of sight between the noise source and the receiving point, except trees and shrubs, which provide very little shielding. Note that the noise source may be above the rail bed, as is indicated in Steps 2 and 3. The barrier might be an embankment or cutting, an earth berm, one or more buildings, or a specially constructed wall. If a wall is constructed for this purpose, it must have an impervious surface with a negligible number of holes or cracks (less than 0.2 percent of the total surface area). The barrier material should weigh at least 5 kg/m^2 (10 kg/m^2 if barrier attenuation is greater than 10 dB).

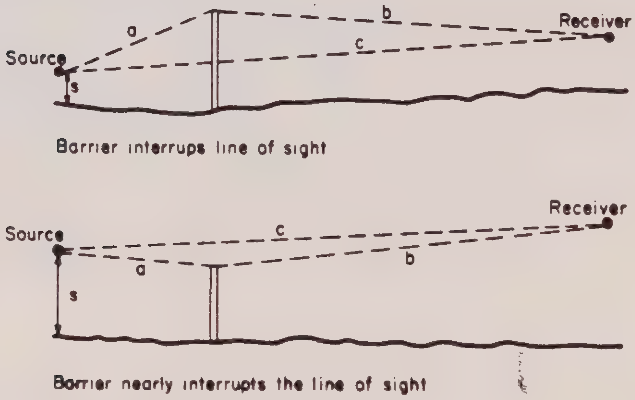
The "barrier attenuation" is the reduction in the noise level at a receiving point relative to the noise level that would exist there if the ground surface were "hard" and if nothing interrupted the path from the noise source to the receiver. Note that the correction for distance when the ground surface is "soft" also depends on the presence or absence of a barrier. Typically, the addition of a barrier provides some barrier attenuation, but reduces the noise level provided by soft ground surface. The trade-off between these two effects must be weighted in assessing the net value of a proposed barrier.

Both the height and the length of a barrier are important to its effectiveness in reducing the noise level. Therefore, both the vertical cross-section and the plan view must be considered. The procedure here first evaluates the attenuation for a barrier of "infinite length" (i.e., a barrier so long that very little noise comes around the ends) considering only the vertical cross-section. The modification of this result to allow for the barrier length and its location relative to the track (as shown in a plan view) is then treated.

Attenuation for a Barrier of Infinite Length

The fundamental barrier geometry is illustrated by Fig. 4b, which is a vertical section along the line from the noise source to the receiving point. The distance "s" is the equivalent height of the noise source above the road surface, which is determined in Steps 2 and 3.

Fig. 4b - Basic barrier model (vertical section)


a
b
c
Source
s
Receiver
Barrier interrups line of sight
Source
c
a
b
s
Receiver
Barrier nearly interrupts the line of sight

For a barrier of infinite length, the attenuation depends on the difference between the straight line distance (c) from source to receiver in Fig. 4b and the combined distance (a + b) from the source to the top of the barrier and then to the receiver. This is called the "path length difference".

Calculating the path length difference is straightforward. The necessary horizontal and vertical distances are indicated in Fig. 4c for the two important cases where the barrier interrupts the line of sight and where the barrier nearly interrupts the line of sight.

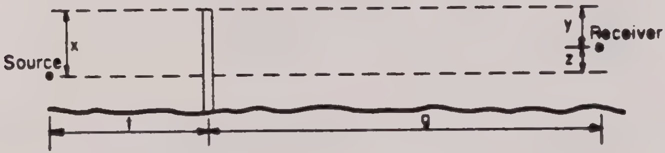
The distances "a", "b", and "c" may be calculated using the expressions:

$$a = \sqrt{x^2 + f^2}$$

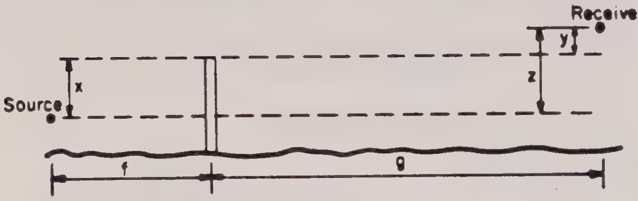
$$b = \sqrt{y^2 + g^2}$$

$$c = \sqrt{z^2 + (f + g)^2}$$

Fig. 4c - Necessary dimensions for calculation of barrier attenuation



Receiver below barrier



Receiver above barrier and source

Note: "x" is the difference in elevation between the source and the top of the barrier. "y" is the difference in elevation between the receiver and the top of the barrier. "z" is the difference in elevation between the source and the receiver.

In calculating the value of c, the horizontal distance used should be the exact sum of the other two horizontal distances; the vertical distances should be the exact sum or difference of x and y, as indicated in Fig. 4c. All the square roots should be calculated to an accuracy of 0.01 m. Note that this does not mean that this accuracy is required in the original distances such as f and g.

(Note: inexpensive electronic calculators which can compute squares and square roots are readily available.)

The path length difference = a + b - c. If the barrier does not interrupt the line of sight from the source to the receiver, and the path length difference is 0.06 m or greater, the barrier attenuation is zero, and no further calculations are required. In other cases, the path length difference may be used with Table 4.6 to obtain the attenuation for a barrier of infinite length.

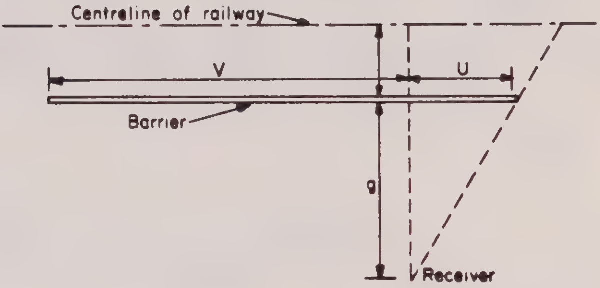
The calculations using the path length difference are appropriate for continuous barriers such as berms, specially constructed fences or row housing. However, some attenuation may also be provided by rows of detached buildings that are sufficiently closely spaced (average space between buildings less than 50 percent of average building length).

For the first row of buildings obstructing the line of sight between the source and the receiving point, allow a barrier attenuation of 4 dB. Further attenuations of 2 dB each may be allowed for the second, third and fourth rows respectively. If both a continuous barrier and one or more rows of buidings are present, an attenuation of 2 dB per row may be allowed for each of the first three rows of buildings interrupting the line of sight from the top of the barrier to the receiving point. The combined attenuation for the continuous barrier and the row(s) of housing may not exceed 20 dB. Note that these attenuations must be corrected for the actual length of the rows of buildings, following the procedure outlined in the next seciton, "Correction for Actual Barrier Length".

Correction for Actual Barrier Length

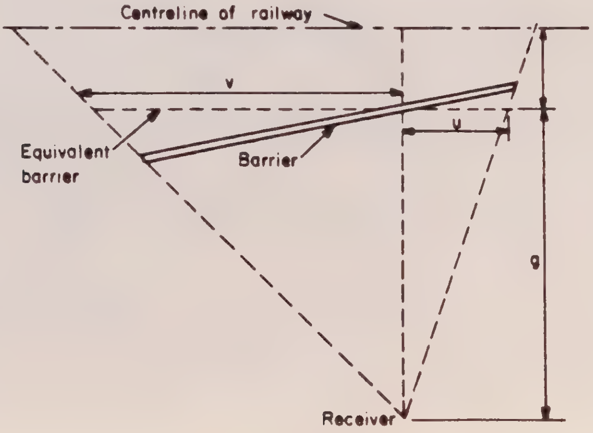
A plan view of a barrier is shown in Fig. 4d. A line from the receiving point to the centreline of the railway divides the barrier into two segments, one of length v and the other of length u.

Fig. 4d - Plan view of railside barrier



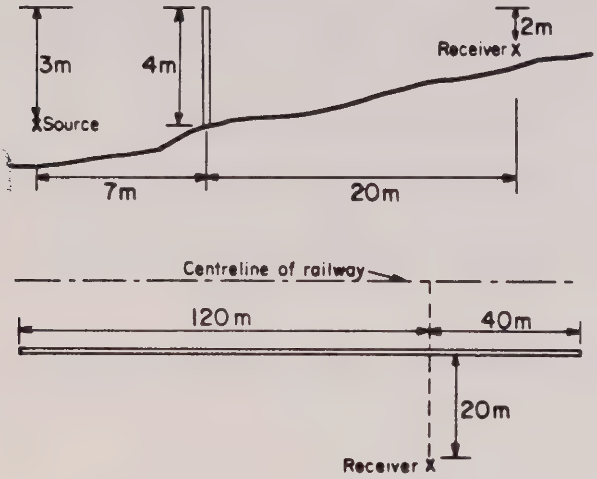
If the barrier is not parallel to the rail track, the procedure is to consider an equivalent barrier parallel to the track, as shown in Fig. 4e. The equivalent barrier is represented by the broken line parallel to the railway and screening the same portion of the railway track.

Fig. 4e - Plan view of an equivalent parallel barrier



The values of these ratios u/g and v/g are used in conjunction with Table 4.5 to determine the effective barrier length ratio (w). If the value of w is less than 10, a significant amount of noise may reach the receiving point via paths around the ends of the barrier. The value of w and the attenuation for a barrier of infinite length, as determined in the previous section, may be used in Table 4.6 to obtain the attenuation for the actual barrier.

Fig. 4f - Numerical example of work procedure



Numerical Example of Work Procedure

In the example in Fig. 4f, the source is 3 m below and 7 m horizontally from the top of the barrier. The direct distance from source to barrier top is:

$$a = \sqrt{(3 \times 3) + (7 \times 7)} = 7.62 \text{ m.}$$

The vertical and horizontal distances from the top of the barrier to the receiver are 2 m and 20 m respectively; the direct distance is

$$b = \sqrt{(2 \times 2) + (20 \times 20)} = 20.10 \text{ m.}$$

The receiving point is 1 m above the source and 27 m away horizontally; the direct source receiver distance is therefore

$$c = \sqrt{(1 \times 1) + (27 \times 27)} = 27.02 \text{ m.}$$

The barrier interrupts the line of sight from the source to receiver and the path length difference is

$$7.62 + 20.10 - 27.02 = 0.70 \text{ m.}$$

For a barrier of infinite length, the barrier attentuation, as given in Table 4.6, would be 13 dB.

From Fig. 4f it is seen that u = 40 m, v = 120 m and g = 20 m. Therefore:

$$u/g = 40/20 = 2$$
$$v/g = 120/20 = 6$$

These values can be used with Table 4.5 to obtain the effective barrier length ratio (w), which if found to be 3.

The path length difference (0.70 m) and the effective barrier length raio (w = 3) can now be used in Table 4.6 to give the barrier attenuation for the actual barrier, which is 10 dB.

Further numerical examples illustrating other common barrier configurations are given in Appendix B.

Step 6 - Calculation of Whistle Noise

Where an audible warning is required, the sounding of the whistle must, by law, start 400 m before and continue up to a point where the warning is necessary. Train speed does not alter the loudness of the whistle noise, but does change the duration of the noise and therefore the noise level.

The noise level at a site depends on the distance from the site to the centreline of the track, and the ditance from that point on the railway to the point where the audible warning is required. Table 4.7 gives the whistle noise level for a single train passing by at 80 km/h (assuming that half the trains approach the warning point from one direction and half from the other).

If the terrain between the railway and the receiving point is reasonably flat and has a soft surface, a "ground attenuation" correction may be applied. For whistle noise, the source is located 4 m above the track, and the distance from the receiving point to the nearest point at which the whistle is sounded is taken as the horizontal distance. Because of the special geometry of the whistle zone, the corrections for distance and for ground attenuation are best treated individually. Distance corrections are incorporated in Table 4.7; the additional ground attentuation correction is given in Table 4.8. Finally, to account for the actual number of trains and their average speed, add the correction in Table 4.9.

Whistle noise may be reduced by the presence of a barrier that interrupts the line of sight between the source and the receiving point. The source of whistle noise is located 4 m above the track. The procedure outlined in Step 5 may be used to calculate the barrier attnuation, except that Fig. 4d is replaced by Fig. 4g or 4h. In this case, the line from the receiver to the nearest point in the whistle zone is divided into two parts, f and g, by the barrier. The line also divides the barrier into two segments, one of the length v and one of length u. If the barrier is not parallel to the railway track, the calculation is done for an equivalent barrier parallel to the track which interesects the line at the same point and screens the same portion of the track. This is illustrated in Fig. 4e. The length g, u and v can then be used as described in Step 5 of "Correction for Actual Barrier Length".

Fig. 4g - Plan view of barrier for whistle noise where receiving point is within whistle zone

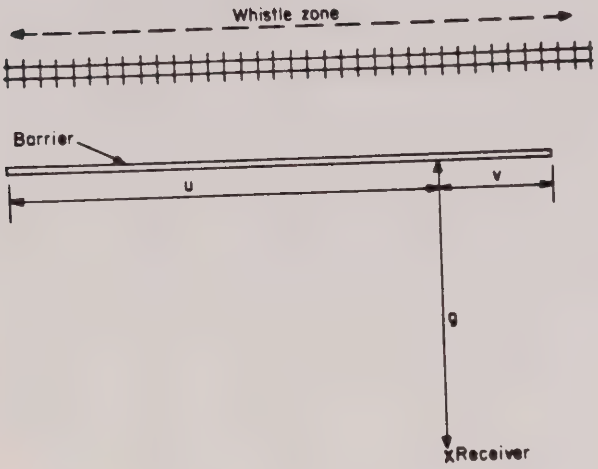


Fig. 4h - Plan view of barrier for whistle noise where receiving point is offset from whistle zone

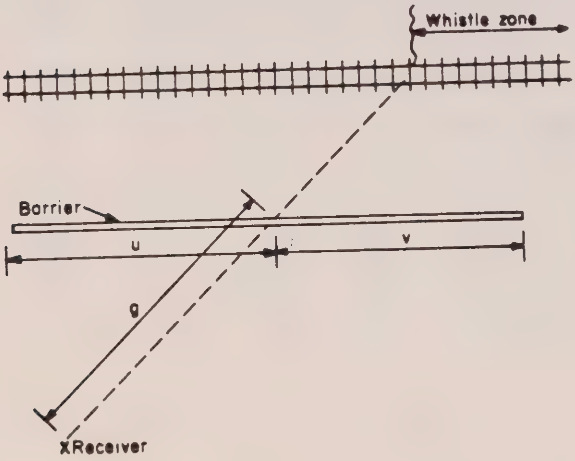


Table 4.1 Engine noise (in dB) at 30 m from track for train speed of 80 km/h

Total number of locomtives per day	Average number of cars/locomotives 1-4	5-11	12-18	19-25	26-32	33-39	40-46	47-53
4 or fewer	50	51	52	53	54	55	56	57
5	51	52	53	54	55	56	57	58
6	52	53	54	55	56	57	58	59
7 - 8	53	54	55	56	57	58	59	60
9 - 10	54	55	56	57	58	59	60	61
11 - 13	55	56	57	58	59	60	61	62
14 - 17	56	57	58	59	60	61	62	63
18 - 22	57	58	59	60	61	62	63	64
23 - 28	58	59	60	61	62	63	64	65
29 - 35	59	60	61	62	63	64	65	66
36 - 45	60	61	62	63	64	65	66	67
46 - 56	61	62	63	64	65	66	67	68
57 - 71	62	63	64	65	66	67	68	69
72 - 90	63	64	65	66	67	68	69	70
91 - 110	64	65	66	67	68	69	70	71
111 - 142	65	66	67	68	69	70	71	72
143 - 180	66	67	68	69	70	71	72	73
181 - 225	67	68	69	70	71	72	73	74

Table 4.2 - Correction (in dB) to engine noise for actual train speed

Actual Train Speed km/h	Up to 34	35-43	44-51	52-61	62-74	75-86	87-105	over 105
Correction (dB)	-5	-4	-3	-2	-1	0	-1	-2

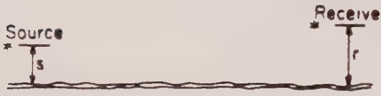
Table 4.3 Wheel-Rail noise (in dB) at 30 m from track

	Train Speed (km/h)												
Total number of railway cars per day	up to 27	28 to 29	30 to 34	35 to 40	41 to 47	48 to 53	54 to 61	62 to 72	73 to 84	85 to 97	98 to 111	112 to 129	over 129
up to 70	42	43	44	45	46	47	48	49	50	51	52	53	54
71 - 90	43	44	45	46	47	48	49	50	51	52	53	54	55
91 - 110	44	45	46	47	48	49	50	51	52	53	54	55	56
111 - 140	45	46	47	48	49	50	51	52	53	54	55	56	57
141 - 180	46	47	48	49	50	51	52	53	54	55	56	57	58
181 - 220	47	48	49	50	51	52	53	54	55	56	57	58	59
221 - 280	48	49	50	51	52	53	54	55	56	57	58	59	60
281 - 350	49	50	51	52	53	54	55	56	57	58	59	60	61
351 - 440	50	51	52	53	54	55	56	57	58	59	60	61	62
441 - 560	51	52	53	54	55	56	57	58	59	60	61	62	63
561 - 700	52	53	54	55	56	57	58	59	60	61	62	63	64
701 - 890	53	54	55	56	57	58	59	60	61	62	63	64	65
891 - 1120	54	55	56	57	58	59	60	61	62	63	64	65	66
1121 - 1400	55	56	57	58	59	60	61	62	63	64	65	66	67
1401 - 1770	56	57	58	59	60	61	62	63	64	65	66	67	68
1771 - 2230	57	58	59	60	61	62	63	64	65	66	67	68	69
2231 - 2800	58	59	60	61	62	63	64	65	66	67	68	69	70

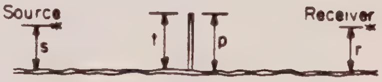
Table 4.4 - Correction (in dB) for distance from source to receiver and for total effective height above ground

Effective Total Height Above Ground (metres)	HORIZONTAL DISTANCE IN METRES FROM SOURCE TO RECEIVING POINT																	
	up to 11	11 to 14	15 to 18	19 to 22	23 to 27	28 to 35	36 to 45	46 to 57	58 to 72	73 to 90	91 to 112	113 to 142	143 to 180	181 to 225	226 to 275	276 to 350	351 to 450	451 or over
	Correction in dB if accoustically "soft surface																	
58.0 or over	+5	+4	+3	+2	+1	0	-1	-2	-3	-4	-5	-6	-7	-8	-9	-11	-13	-15
45.1 to 57.0	+5	+4	+3	+2	+1	0	-1	-2	-3	-4	-5	-6	-7	-8	-10	-12	-14	-16
36.1 to 45.0	+5	+4	+3	+2	+1	0	-1	-2	-3	-4	-5	-6	-7	-9	-11	-13	-15	-17
28.1 to 36.0	+5	+4	+3	+2	+1	0	-1	-2	-3	-4	-5	-6	-8	-10	-12	-14	-16	-18
22.1 to 28.0	+5	+4	+3	+2	+1	0	-1	-2	-3	-4	-5	-7	-9	-11	-13	-15	-17	-19
18.1 to 22.0	+5	+4	+3	+2	+1	0	-1	-2	-3	-4	-6	-8	-10	-12	-14	-16	-18	-20
14.1 to 18.0	+5	+4	+3	+2	+1	0	-1	-2	-3	-5	-7	-9	-11	-13	-15	-17	-18	-20
11.1 to 14.0	+5	+4	+3	+2	+1	0	-1	-2	-4	-6	-8	-10	-12	-14	-16	-17	-19	-21
9.1 to 11.0	+5	+4	+3	+2	+1	0	-1	-3	-5	-7	-9	-11	-13	-15	-17	-18	-20	-21
7.1 to 9.0	+5	+4	+3	+2	+1	0	-2	-4	-6	-8	-10	-12	-14	-16	-17	-19	-20	-22
5.6 to 7.0	+5	+4	+3	+2	+1	-1	-3	-5	-7	-9	-11	-13	-14	-16	-18	-19	-20	-22
4.1 to 5.5	+5	+4	+3	+2	0	-2	-4	-6	-8	-10	-12	-14	-15	-17	-18	-20	-21	-23
2.6 to 4.0	+5	+4	+3	+1	0	-2	-4	-6	-8	-10	-12	-14	-16	-18	-19	-21	-22	-24
up to 2.5	+5	+4	+3	+1	-1	-3	-5	-7	-9	-11	-13	-15	-17	-19	-21	-22	-23	-25
	Correction in dB if accoustically "hard" surface																	
All Heights	+5	+4	+3	+2	+1	0	-1	-2	-3	-4	-5	-6	-7	-8	-9	-10	-11	-12

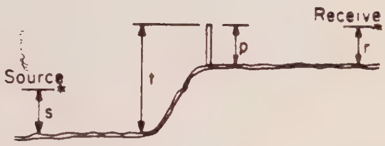
Effective total height above ground



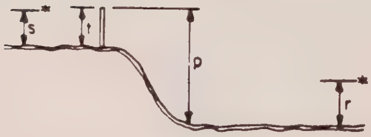
No barrier-effective total height=s+r



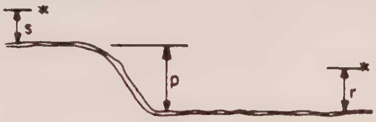
With barrier-effective total height =s+t+p+r



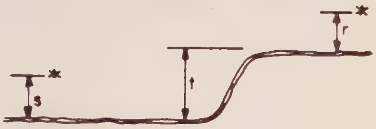
With barrier (depressed road) -effective total height=s+t+p+r



With barrier (depressed site) -effective total height=s+t+p+r



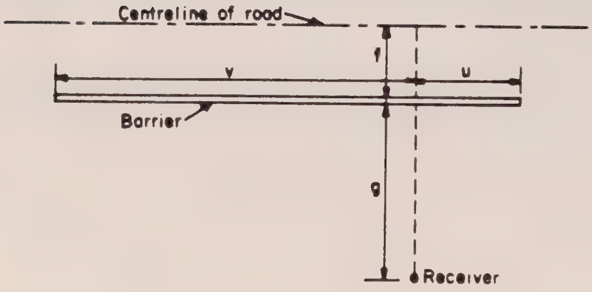
Effective total height=s+p+r



Effective total height=s+t+r

Table 4.5 - Effective barrier length ratio (w) for asymmetric barriers

Ratio v/g	Ratio u/g															
	over 9.5	8.6 to 9.5	7.6 to 8.5	6.6 to 7.5	5.6 to 6.5	4.6 to 5.5	3.6 to 4.5	2.8 to 3.5	2.3 to 2.7	1.8 to 2.2	1.3 to 1.7	0.9 to 1.2	0.6 to 0.8	0.36 to 0.5	0.15 to 0.35	less than 0.15
over	10.0	9.0	9.0	8.0	7.0	6.0	5.0	4.0	4.0	3.0	2.0	1.5	1.0	1.0	0.7	0.7
8.6 - 9.5	9.0	9.0	8.0	7.0	7.0	6.0	5.0	4.0	4.0	3.0	2.0	1.5	1.0	1.0	0.7	0.7
7.6 - 8.5	9.0	8.0	8.0	7.0	7.0	6.0	5.0	4.0	4.0	3.0	2.0	1.5	1.0	1.0	0.7	0.7
6.6 - 7.5	8.0	7.0	7.0	7.0	6.0	6.0	5.0	4.0	3.0	3.0	2.0	1.5	1.0	1.0	0.7	0.7
5.6 - 6.5	7.0	7.0	7.0	6.0	6.0	5.0	5.0	4.0	3.0	3.0	2.0	1.5	1.0	1.0	0.7	0.7
4.6 - 5.5	6.0	6.0	6.0	6.0	5.0	5.0	4.0	4.0	3.0	3.0	2.0	1.5	1.0	1.0	0.7	0.7
3.6 - 4.5	5.0	5.0	5.0	5.0	5.0	4.0	4.0	3.0	3.0	2.5	2.0	1.5	1.0	1.0	0.7	0.7
2.8 - 3.5	4.0	4.0	4.0	4.0	4.0	4.0	3.0	3.0	2.5	2.5	2.0	1.5	1.0	1.0	0.7	0.7
2.3 - 2.7	4.0	4.0	4.0	4.0	4.0	3.0	3.0	2.5	2.5	2.0	2.0	1.5	1.0	1.0	0.7	0.7
1.8 - 2.2	3.0	3.0	3.0	3.0	3.0	3.0	2.5	2.5	2.0	2.0	1.5	1.5	1.0	1.0	0.7	0.7
1.3 - 1.7	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	1.5	1.5	1.0	1.0	1.0	0.7	0.7
0.9 - 1.2	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.0	1.0	0.7	0.7	0.7	0.5
0.6 - 0.8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.7	0.7	0.5	0.5	0.3
0.36- 0.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.7	0.5	0.5	0.3	0.0
0.15- 0.35	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.5	0.3	0.3	0.0
less than 0.15	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.5	0.3	0.0	0.0	0.0



Note: 1) Where both u/g and v/g are greater than 15, the barrier shall be treated as a barrier of infinite length.

Table 4.6 - Barrier attenuation (in dB) for various values of the effective barrier length ratio (w)

Path Length Difference (in metres)		Effective Barrier Length Ratio (w)															Infinite Length
		0.3	0.5	0.7	1.0	1.5	2.0	2.5	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	
		Barrier Attenuation (in dB)															
barrier	0.06	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
does not	0.05	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
interrupt	0.04	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	2
line of	0.03	1	2	2	2	3	3	3	3	3	3	3	3	3	3	3	3
sight	0.02	1	2	2	3	4	4	4	4	4	4	4	4	4	4	4	4
	0.00	1	2	2	3	4	5	5	5	5	5	5	5	5	5	5	5
	0.03	1	2	3	4	5	6	6	6	6	6	6	6	6	6	6	6
barrier	0.07	1	2	3	4	5	6	6	6	7	7	7	7	7	7	7	7
does	0.13	1	2	3	4	6	7	7	7	8	8	8	8	8	8	8	8
interrupt	0.20	1	2	3	4	6	7	7	8	9	9	9	9	9	9	9	9
line of	0.30	1	2	3	4	6	7	8	9	9	10	10	10	10	10	10	10
sight	0.41	1	2	3	4	6	7	8	9	10	10	11	11	11	11	11	11
	0.55	1	2	3	4	6	8	9	10	11	11	12	12	12	12	12	12
	0.79	1	2	3	4	6	8	9	10	11	11	12	12	12	12	12	13
	1.0	1	2	3	4	6	8	9	10	11	12	12	13	13	13	13	14
	1.4	1	2	3	4	6	8	9	10	11	12	12	13	14	14	14	15
	1.8	1	2	3	4	6	8	9	10	12	13	13	14	14	14	15	16
	2.5	1	2	3	4	6	8	9	10	12	13	14	15	15	15	16	17
	3.3	1	2	3	4	6	8	9	11	12	13	15	15	16	16	17	18
	4.5	1	2	3	4	6	8	9	11	12	14	15	16	17	17	18	19
	6.0	2	3	4	5	7	8	10	11	13	15	16	17	18	18	19	20

Source: National Research Council of Canada, Division of Building Research, June, 1980.

NOTE: 1) Where the calculated path length difference is not found in the table, the nearest value in the table should be used.

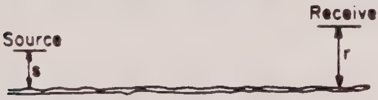
Table 4.7 - Whistle noise (in dB) for a single train travelling at 80 km/h if ground surface is "hard"

Shortest Distance To Track In Metres	Distance along track from warning point in metres														
	up to 320	321 to 365	366 to 395	396 to 417	418 to 432	433 to 447	448 to 462	463 to 477	478 to 502	503 to 535	536 to 565	566 to 602	603 to 655	656 to 715	716 or over
up to 13	59	58	57	53	50	48	47	46	45	44	42	41	40	39	38
14 - 16	58	57	56	53	50	48	47	46	45	44	42	41	40	39	38
17 - 21	57	56	55	52	50	48	47	46	45	43	42	41	40	39	38
22 - 27	56	55	54	52	50	48	47	46	45	43	42	41	40	39	38
28 - 33	55	54	53	51	49	48	47	46	45	43	42	41	40	39	38
34 - 40	54	53	52	50	49	48	46	46	45	43	42	41	40	39	38
41 - 47	53	52	51	49	48	47	46	46	45	43	42	41	40	39	38
48 - 55	52	51	50	49	48	47	46	45	44	43	42	41	40	39	38
56 - 65	51	50	49	48	47	47	46	45	44	43	42	41	40	39	38
66 - 80	50	49	48	48	47	46	45	44	44	43	42	41	40	39	38
81 - 97	49	48	47	47	46	45	44	44	43	42	41	41	40	39	38
98 - 115	48	47	46	46	46	45	44	44	43	42	41	41	40	39	38
116 - 135	47	46	45	45	45	44	44	43	43	41	41	40	39	38	38
136 - 165	46	45	44	44	44	43	43	43	42	41	41	40	39	38	38
166 - 195	45	44	43	43	43	43	42	42	42	41	41	40	39	38	37
196 - 225	44	43	43	43	42	42	42	42	42	41	40	40	38	38	37
226 - 260	43	42	42	42	42	41	41	41	41	40	40	39	38	38	37
261 - 295	42	42	41	41	41	41	41	41	41	40	39	38	38	37	36
296 - 340	41	41	41	41	40	40	40	40	40	39	39	38	37	37	36
341 - 400	40	40	40	40	39	39	39	39	39	38	38	37	37	36	36
401 - 460	39	39	39	39	39	38	38	38	38	37	37	37	36	36	35
461 or over	39	38	38	38	38	38	38	37	37	37	37	37	36	36	35

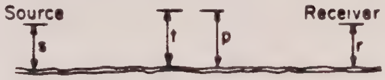
Table 4.8 - Correction (in dB) to be subtracted from whistle noise level if ground is "soft"

Effective Total Height Above Ground In Metres	Shortest horizontal distance to track in metres up to 14	15 to 18	19 to 22	23 to 27	28 to 35	36 to 45	46 to 57	58 to 72	73 to 90	91 to 112	113 to 142	143 to 180	181 to 225	226 to 275	276 to 350	351 to 450	451 to over
58.0 or over	0													0	1	2	3
45.1 to 57.0	0												0	1	2	3	4
36.1 to 45.0	0											0	1	2	3	4	5
28.1 to 36.0	0										0	1	2	3	4	5	6
22.1 to 28.0	0									0	1	2	3	4	5	6	7
18.1 to 22.0	0								0	1	2	3	4	5	6	7	8
14.1 to 18.0	0							0	1	2	3	4	5	6	7	7	8
11.1 to 14.0	0						0	1	2	3	4	5	6	7	7	8	9
9.1 to 11.0	0					0	1	2	3	4	5	6	7	8	8	9	9
7.1 to 9.0	0				0	1	2	3	4	5	6	7	8	8	9	9	10
5.6 to 7.0	0			0	1	2	3	4	5	6	7	7	8	9	9	10	10
4.1 to 5.5	0		0	1	2	3	4	5	6	7	8	8	9	9	10	10	11

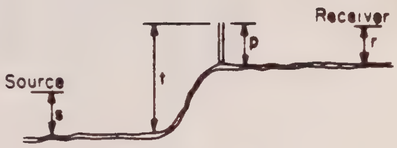
Effective total height above ground



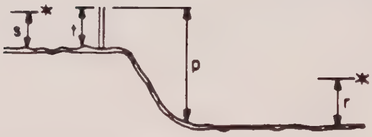
No barrier-effective total height=s+r



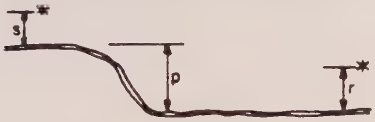
With barrier-effective total height =s+t+p+r



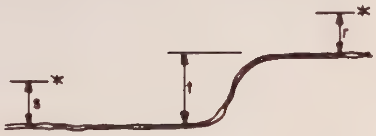
With barrier (depressed road) -effective total height=s+t+p+r



With barrier (depressed site)



Effective total height=s+p+r



Effective total height=s+t+r

Table 4.9 - Correction (in dB) to whistle noise for train speed and number of trains per day

Number of trains per day	Actual train speed (km/h)							
	up to 27	28 to 35	36 to 45	46 to 56	57 to 72	73 to 90	91 to 114	above 114
1	5	4	3	2	1	0	-1	-2
2	8	7	6	5	4	3	2	1
3	10	9	8	7	6	5	4	3
4	11	10	9	8	7	6	5	4
5	12	11	10	9	8	7	6	5
6	13	12	11	10	9	8	7	6
7- 8	14	13	12	11	10	9	8	7
9- 10	15	14	13	12	11	10	9	8
11- 13	16	15	14	13	12	11	10	9
14- 17	17	16	15	14	13	12	11	10
18- 22	18	17	16	15	14	13	12	11
23- 28	19	18	17	16	15	14	13	12
29- 35	20	19	18	17	16	15	14	13
36- 45	21	20	19	18	17	16	15	14
46- 56	22	21	20	19	18	17	16	15
57- 71	23	22	21	20	19	18	17	16
72- 90	24	23	22	21	10	19	18	17
91-110	25	24	23	22	21	20	19	18
111-142	26	25	24	23	22	21	20	19
143-180	27	26	25	24	23	22	21	20
181-225	28	27	26	25	24	23	22	21

COMBINING NOISE LEVELS

Contents

Noise Levels From Single and Multiple Sources

Introduction
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Example of Combined Levels for Several Sources

Table

5.1 Corrections for combining noise levels, expressed in dB

Noise Levels From Single and Multiple Sources

Introduction

In Parts 3 and 4, methods were developed for predicting the noise level on a proposed building site made by traffic on a nearby road or railway. Two further points must be considered in determining the noise exposure of the building:

- Because the building itself shields some facades from an adjacent traffic route, each building wall should be considered separately to determne the incident noise level and hence the required sound insulation.
- Because, in many cases, more than one road or railway contributes to the noise level at a building wall, a procedure is required for combining the contributions from a number of sources.

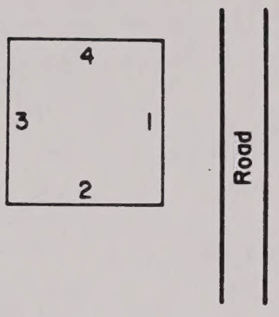
Noise Levels from a Single Source

The noise level for a building wall facing a traffic route may be calculated by following the steps outlined in Parts 3 or 4. The noise levels for the flanking walls perpendicular to the roadway (Walls 2 and 4 in the diagram below) are 3 dB lower because the building screens these walls from half the noise source. The building provides additional screening of 15 dB for the wall sheltered from the road or railway.

The same rules may be applied to a single row of buildings parallel to a traffic route. If additional buildings are present, from which noise may be reflected to the "sheltered" wall (Wall 3 in the diagram), only a 10 dB reduction relative to the noise level at Wall 1 should be allowed.

Example: If the calculation in Section 3 gave a value of 67 dB at Wall 1, for the building shown in the diagram below, the levels at the four walls would be:

67dB at Wall 1
64dB at Wall 2
64dB at Wall 4
52dB at Wall 3



NOTE: For larger buildings, such as row houses, it may be necessary to allow for the reduction of noise as distance from the road or railway increases. A sample calculation is given in Appendix E - Example E.4.

Combination of Levels from Multiple Sources

When the noise reaching a building wall comes from a number of sources, first establish the noise level from each individual source and then combine the levels progressively, following the procedure given below. Because the noise levels are expressed in decibels, they cannot be added directly. To combine the levels for two sources, first determine the numerical difference between the levels, and then add to the higher level the appropriate correction from Table 5.1. The effect of the third source may be included by repeating the calculation to combine the third level with the result for the first two levels, and so on for additional sources.

Example: To determine the combined level for Level A - 59 dB, Level B - 65 dB and Level C - 69 dB.

The difference between Level A and Level B is 6 dB.

Correction from Table 5.1	1 dB
Higher of the two levels	65 dB
Combined Levels A and B	66 dB

The difference between this combined level and Level C is 3 dB.

Correction from Table 5.1	2 dB
Higher of the two levels	69 dB
	71 dB

Thus the total combined level is 71 dB.

Example of Combined Levels for Several Sources

The building illustrated in the diagram on the right is influenced by noise from road A, road B and railway C. the noise level for each source would be determined as in Parts 3 and 4. Suppose that the noise level at Wall 1 from road A was calculated to be 65 dB; then at the mid-points of Walls 2 and 4, road A would contribute 62 dB and on Wall 3 the contribution would be 50 dB. Similarly, noises reaching Wall 2 from road B and railway C might be 66 dB and 70 dB respectively, and on

Wall 1 and 3, 63 and 67 dB. The noise levels at the four walls are then determined by combining levels, using Table 5.1, with the results shown below.

Source	Wall 1	Wall 2	Wall 3	Wall 4
Road A	65 dB	62 dB	50 dB	62 dB
Road B	63 dB	66 dB	63 dB	51 dB
Railway C	67 dB	70 dB	67 dB	55 dB
Combined Level	70 dB	72 dB	69 dB	63 dB

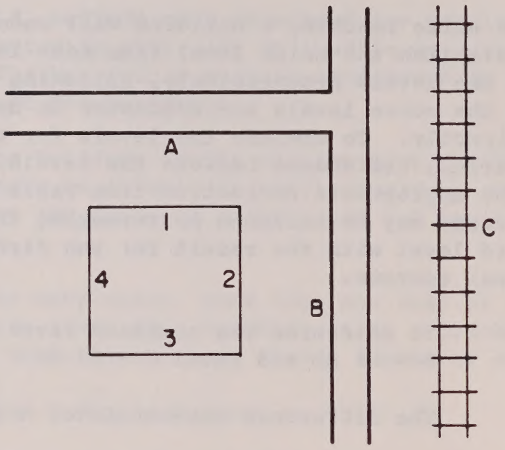


Table 5.1 - Corrections for combining noise level expressed in dB

If higher level exceeds lower level by	Add this correction to higher level
0 - 1 dB	3 dB
2 - 4 dB	2 dB
5 - 9 dB	1 dB
over 10 dB	0 dB